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TECHNICAL PROGRESS REPORT

CONTRACT DA-36-034-ORD-3296 RD

ORDNANCE CORPS PROJECT NUMBER — OMS 5010.1180 800.51.03

PREPARED FOR

U. S. ARMY ORDNANCE DISTRICT
PHILADELPHIA, PA.

UNDER

TECHNICAL SUPERVISION — FRANKFORD ARSENAL
CONTROL NO. A5180

DEVELOPMENT OF HIGH PERFORMANCE ROCKET MOTOR CASE

FINAL SUMMARY REPORT NUMBER 23

Period – June 21, 1960 to November 30, 1962

PRODUCT DEVELOPMENT DEPARTMENT
THE BUDD COMPANY
Philadelphia 32, Pennsylvania

THE Budd COMPANY

PHILADELPHIA 32, PA.

PRODUCT DEVELOPMENT

ENGINEERING

Final Summary Report No. 23

Period: June 21, 1960 to November 30, 1962

Contract: DA36-034-ORD-3296RD

Ordnance Corps Project No.: OMS-5010-1180800-51-03

ROCKET MOTOR CASE DEVELOPMENT

Control No. A-5180

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8600-255-2434

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ABSTRACT

This is the twenty-third, and Final Summary Report, covering the work conducted by The Budd Company on the development of a high performance rocket motor case under Contract DA36-034-ORD-3296RD. This report also covers in detail the period June 21, 1960 to November 30, 1962. Work accomplished during the second calendar quarter of fiscal year 1962 is included in this report. All of the work on this contract has been reported in monthly and quarterly reports. Therefore, this final report will summarize the results and conclusions obtained.

The development of metal rocket motor cases, having high strength to weight ratios, has been limited by two major factors:

1. Availability of alloys, having high strength to density ratios.

2. A suitable method of fabricating high strength alloys with reasonable ease and economy to take full advantage of the material properties.

The objective of this contract is the development of a solid propellant rocket case having the following characteristics:

1. A case length to diameter ratio of two to one.

2. The case shall have an overall ultimate strength to weight ratio of 1×10^6 inches or more.

3. The design of the case shall utilize sheet or strip metal in a condition of maximum usable strength and requiring a minimum of post fabrication heat treatment.

In a program to attain the objectives set forth under the contract, The Budd Company has:

1. Completed a comprehensive survey and evaluation of 12 alloys having properties and suitability for potential application to a rocket motor case design.

2. Selected and obtained quantities of the two most appropriate alloys - International Nickel Corporation's 20% nickel mar-aging steel and the all beta titanium alloy Ti 13V-11Cr-3Al. Each has an ultimate strength to weight ratio of 1×10^6 inch or more.

3. Conceived a new helical welded cylindrical case design to make use of the high strength properties of the new alloys.

4. **Developed a process, designed and built experimental production tooling and equipment to economically fabricate the helical welded cylindrical case.**

5. **Developed a process, designed and built tooling to successfully deep draw, at room temperatures, elliptical heads having high thickness to diameter ratios, using 20% nickel mar-aging steel and Ti 13V-11Cr-3Al alloys.**

6. **Fabricated two 20 inch diameter X 40 inch long test pressure vessels of the helical welded design from 20% nickel mar-aging steel.**

7. **Sectioned one 20 inch diameter X 40 inch long test pressure vessel for metallurgical studies.**

8. **Hydrostatic pressure tested one 20 inch diameter X 40 inch long test pressure vessel to burst, which failed prematurely, due to material surface defects. At this point work was terminated due to expiration of funds.**

SUMMARY CONCLUSIONS

The accomplishments attained on this rocket case development clearly indicate:

1. That using the nickel mar-aging steels available, or will be available in the near future, it is possible to design and build reliable rocket cases having an ultimate strength to weight ratio of 1×10^6 inch or greater.

2. That using the design and fabrication techniques developed, significant cost savings are possible through major reductions in machining, heat treatment, and need for special equipment.

3. That the feasibility of deep drawing high thickness to diameter ratio elliptical and spherical heads from high strength alloys has been established.

4. That high weld reliability is possible by controlling the variables affecting welds and controlling the processing of the alloy, together with a design concept wherein the welds are operating at a safe margin below their maximum attainable yield strength.

5. That equipment designed for this development can and has been applied to the manufacture of high strength thin wall cylinders of large diameters and lengths for applications other than rocket cases.

6. That fabrication and satisfactory hydrostatic burst tests of additional pressure vessels of this design can be made to demonstrate the adequacy and utility of this design concept and fabrication process using the currently best established high strength nickel mar-aging steel alloy: 18% nickel; 9% cobalt; 5% molybdenum.

INTRODUCTION

The Department of Defense established in 1960 a research and development program, under the direction of the Ordnance Materials Research Office, Watertown Arsenal, to obtain a significant advance in material properties and fabrication techniques as applied to the inert components of large diameter, high performance, solid propellant rocket motors. The work was not directed to any specific missile or rocket motor, but rather to obtain improvement in the state of the art.

The primary objective was to develop a rocket motor casing capable of withstanding hoop stresses substantially in excess of the 200,000 psi - 220,000 psi range, currently being attained in production cases.

The contract awarded to The Budd Company, under the technical direction of Frankford Arsenal, had as its objective the material selection, design, fabrication and test of a large diameter non-monolithic motor case which would take advantage of the high strength properties and quality available in strip or sheet alloys.

A program was established under the direction of the Technical Supervisor, Frankford Arsenal, to attain the objectives desired. This program is outlined below:

1. Materials Investigation - Determine from prime material producers the availability of ferrous and nonferrous alloys having the properties required to meet design objectives.

2. Materials Evaluation - A comprehensive evaluation of the properties of available alloys considered applicable to the rocket case design. Tensile properties, fracture toughness, weldability and formability are the principal characteristics to be studied.

3. Evaluation of Welded Joint Designs - Uniaxial specimens of welded joint configurations representing cylindrical shell and head to shell connections will be tested. Effect of various heat treatments on the joint efficiency are evaluated.

4. Develop a fabrication method for forming high thickness diameter ratio spherical and elliptical heads from sheet alloys.

5. Design, fabricate and test 20 inch diameter cases using selected alloys. Full scale material thickness to be used in subscale design.

6. Extend design and fabrication methods to full scale 40 inch diameter case.

Data developed in the two year period of the program and reported in monthly and quarterly reports are reviewed in this final report.

The results of work accomplished during the second calendar quarter 1962 on the fabrication of 20 inch tests, cases made from 20% nickel mar-aging steel are included.

At the start of the contract, a program outline was made for review with the Technical Supervisor, Frankford Arsenal. The program was mainly an extension of prior work done at The Budd Company on rocket cases designed around AM-355 alloy, employing spotwelded doublers to reinforce the low weld strength areas. The concept was the basis for the Budd proposal to the Government.

The initial outline was changed on the recommendation of Frankford Arsenal to a program wherein the first year would be primarily devoted to investigation and evaluation of new metal alloys. This was to be followed by design and construction of test cases using material selected from the evaluation. The subsequent evaluation of the nickel mar-aging steels and beta titanium alloys showed that weld strengths could be attained, either in the as welded condition or utilizing a mild aging treatment. This would eliminate the necessity of weld reinforcements and their resultant discontinuities. The weight saving is a major advantage.

A materials investigation and evaluation was initiated. A thorough canvass of major ferrous and nonferrous alloy producers was made and 12 alloys were found which met the mechanical properties and availability requirements established. A metallurgical evaluation of these alloys resulted in the selection of two for application to the case design. The International Nickel Company's 20% nickel mar-aging steel (special high titanium and aluminum analysis) and the all beta

titanium 13V-11Cr-3Al alloy were selected.

A qualitative analysis was made of many possible designs of the selected alloys. A helical butt welded cylinder having the weld line oriented 11° to the direction of maximum stress was selected. The high weld strength attainable with the 20% nickel mar-aging steel and the beta titanium was a major consideration in the design selection.

The development of a welding process to fabricate helical butt welded cylinders followed. This was accomplished in two steps: First, a rig-up fixture was made to produce ten inch diameter cylinders and establish the welding technique; and, second, the design and construction of equipment to weld a 20 inch diameter cylinder from 12 inch wide strip. This equipment was designed to accurately control the variables affecting weld quality.

At the same time a process to form hemispherical and elliptical heads at room temperature from the alloys selected was developed. Elliptical heads were made in ten inch diameter and 20 inch diameter sizes. Ten inch diameter heads of .030 thickness and 20 inch diameter heads of .060 thickness were formed in both the 20% nickel and beta titanium alloys. Since both alloys had relatively low elongation in the annealed condition and the thickness to diameter ratios were high, the process was a significant advance in the state of the art.

Manufacture of two cases, 20 inches in diameter of 20% nickel steel, with an elliptical head on one end and a flat test closure on the other end, for hydrotest, was accomplished. Hydrotest procedures

and support rigging was completed.

Evaluation of control specimens, which accompanied the test case through process heat treatment, indicated a variable and low strength in the helical weld of the cylindrical section. The high weld strength values obtained in prior evaluation of the 20% nickel alloy were not obtained in the case. Strengths of welds in all other areas, including cylinder base metal, head base metal, and head to shell welds, were satisfactory.

Because of the low strength values in the helical weld, hydrotest of the cases was held up. Sectioning of one case confirmed the control specimen results.

A program was initiated to determine the cause of the low strength helical welds. A recheck of weld techniques and variables between good specimens made during evaluation, and these applied to the case, was made. The assistance of International Nickel Company and Allegheny-Ludlum Steel Corporation, who furnished the material, was obtained. Rechecks of base metal and weld wire chemistries are being made by both INCO and Allegheny-Ludlum. Effort was continued to obtain the solution to the problem until funds were exhausted.

One 20 inch diameter case was fabricated for hydrotest employing a modification of the heat treat procedure which circumvented the low weld strength problem. It was determined, by testing of uniaxial specimens, that aging the 20% nickel strip at the standard 900°F temperature, followed by welding and a low temperature aging treatment, the weld strengths were consistent and values were

satisfactory for the design. This case was hydrotested and failure occurred at 63% of the base metal yield strength, due to a series of surface defects in the base metal. The welds performed satisfactorily at the pressures attained.

At the request of the Technical Advisor, a subcontract of one year duration was let to Massachusetts Institute of Technology to continue work on controlled ingot solidification. Effects of the solidification process on properties of sheet metal AISI 4340 and 25% nickel steel were studied. The Budd Company completed a portion of the work on the 4340 material, but Frankford Arsenal assumed the testing and reporting of results on the balance of the 4340 and all of the 25% nickel. Preparation of the final report is in process at M.I.T. at this writing, therefore, results of the work on the subcontract will be covered in a later supplement.

MATERIALS INVESTIGATION

Previous rocket motor case work, conducted by The Budd Company, centered around designs using cold rolled type 301 stainless steel or Allegheny-Ludlum's AM-355 alloys. These alloys attained high strength properties from the cold reduction and/or aging treatment, However, weld yield strengths of these alloys were low, and practical methods for restoring the weld strength to a level approaching base metal strengths have not been fully developed. Reinforcement of the weld area is therefore required in the form of doublers or locally increased thickness. This, of course, imposes a severe design and weight penalty.

In setting up the development program, it was recommended and concurred in by the Technical Supervisor, Frankford Arsenal, a search be

conducted for new high strength alloys with properties suited to The Budd Company design concept.

An investigation was immediately initiated with prime ferrous and nonferrous metal producers, primarily in their research groups, to find suitable alloys. Maximum strength to density ratios and availability in strip or sheet form were the major characteristics sought during the investigation. We made every effort to encourage the mills to bring up for discussion any alloy developed, even though the alloy may have been unsuited for some prior application, such as aircraft.

Table 1 is a summary of alloys considered and their strength to density ratios, as a result of the materials investigation, for application to rocket motor cases.

Selection of alloys for evaluation was limited, where possible, to one alloy from each type, i.e. a typical alloy where strength improvement results from cold reduction, or one of the precipitation hardening alloys. This reduced the amount and possible duplication of testing.

MATERIALS EVALUATION

A comprehensive metallurgical evaluation of the alloys selected from the investigation was initiated to screen the materials and obtain design and processing data for use in subsequent case development.

Table 2 is a summary of materials ordered for evaluation.

COMPARATIVE STRENGTH TO DENSITY RATIOS OF MATERIALS CONSIDERED FOR WRAPPED ROCKET MOTOR CASES

Material	Condition	Typical Ult. Tensile Strength	Density Lbs./Cu.In.	Strength Density Ratio
Stainless Steel				
Allegheny Ludlum AM-357	CRT (50% Reduction)	310,000	.286	1.08×10^6
	SCCRT (20% to 30% Reduction)	320,000	.286	1.12×10^6
AM-359	SCT	220,000	.286	0.77×10^6
Jones and Laughlin JLS-300	Cold Rolled and Aged	345,000	.285	1.21×10^6
Armco PH 12-8-6	Heat Treated	290,000	.282	1.03×10^6
Titanium				
Titanium Corp. of America Ti 13V-11Cr-3Al	Aged	200,000	.175	1.14×10^6
Ti 13V-11Cr-3Al	Cold Rolled and Aged	200,000	.175	1.14×10^6
	Cold Rolled and Aged	230,000	.175	1.32×10^6
Reactive Metals Ti 6Al, 6V, 2Sn	Heat Treated	200,000	.162	1.23×10^6

TABLE 1 (Continued)

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COMPARATIVE STRENGTH TO DENSITY RATIOS OF MATERIALS
CONSIDERED FOR WRAPPED ROCKET MOTOR CASES

Material	Condition	Typical Ult. Tensile Strength	Density Lbs./Cu.In.	Strength Density Ratio
Republic Steel Corp. Ti 8Al-10V	Heat Treated	220,000	.162	1.36×10^6
Nickel Steels				
Allegheny Ludlum 20% Nickel Steel	Heat Treated	265,000	.282	0.94×10^6
25% Nickel Steel	Heat Treated	264,000	.282	0.94×10^6
20% Nickel Steel (Modified Analysis)	Heat Treated	300,000	.282	1.06×10^6
25% Nickel Steel (Modified Analysis)	Heat Treated	300,000	.282	1.06×10^6
20% Nickel Steel (Modified Analysis)	Cold Rolled	315,000	.282	1.12×10^6
25% Nickel Steel (Modified Analysis)	Cold Rolled	315,000	.282	1.12×10^6
Low Alloy Steels				
Experimental Alloy Medium-Low Carbon	Special Process	360,000	.283	1.27×10^6
Experimental Alloy Medium-High Carbon	Special Process	430,000	.283	1.52×10^6

TABLE 1 (Continued)

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MATERIALS ORDERED FOR EVALUATION

Material	Condition	Supplier	Thickness	Min. Sq. Ft.	Budd Purchase Order Number
20% Nickel Steel	Mod.Cr. (300,000 UTS)	Allegheny Lud.	.030	40	3725
20% Nickel Steel	Mod.Cr. (300,000 UTS)	Allegheny Lud.	.060	40	3725
25% Nickel Steel	Mod.Cr. (300,000 UTS)	Allegheny Lud.	.030	40	3725
25% Nickel Steel	Mod.Cr. (300,000 UTS)	Allegheny Lud.	.060	40	3725
25% Nickel Steel	Annealed	Allegheny Lud.	.060	40	3257
25% Nickel Steel	Annealed	Allegheny Lud.	.125	80	3257
25% Nickel Steel	Annealed	Allegheny Lud.	.250	30	3257
20% Nickel Steel	Annealed	Allegheny Lud.	.060	80	3256
20% Nickel Steel	Annealed	Allegheny Lud.	.125	80	3256
20% Nickel Steel	Annealed	Allegheny Lud.	.250	30	3256
Ti 6Al-6V-2Sn	Annealed	R. M. I.	.120	120	3487
PH-12-8-6	Annealed	Armco	.062	80	3550
PH-12-8-6	Annealed	Armco	.125	80	3550
Ti 13V-11Cr-3Al	CR (200,000 UTS)	Timco	.030	30	3290
Ti 13V-11Cr-3Al	CR (200,000 UTS)	Timco	.060	30	3290

TABLE 2 (Continued)

MATERIALS ORDERED FOR EVALUATION

Material	Condition	Supplier	Thickness	Min. Sq. Ft.	Budd Purchase Order Number
Ti 13V-11Cr-3Al	CR (230,000 UTS)	Timco	.030	30	3290
Ti 13V-11Cr-3Al	CR (230,000 UTS)	Timco	.060	30	3290
Ti 13V-11Cr-3Al	Annealed	Timco	.080	10	3290
Ti 13V-11Cr-3Al	Annealed	Timco	.060	80	3290
Ti 13V-11Cr-3Al	Annealed	Timco	.125	80	3290
25% Nickel Steel	Mod.-Annealed	Allegheny Lud.	.060	80	3725
25% Nickel Steel	Mod.-Annealed	Allegheny Lud.	.125	80	3725
25% Nickel Steel	Mod.-Annealed	Allegheny Lud.	.250	30	3725
20% Nickel Steel	Mod.-Annealed	Allegheny Lud.	.060	80	3725
20% Nickel Steel	Mod.-Annealed	Allegheny Lud.	.125	80	3725
20% Nickel Steel	Mod.-Annealed	Allegheny Lud.	.250	30	3725
AM-357	Annealed	Allegheny Lud.	.250	30	3294
AM-357	*CRT (300,000 Y.S.)	Allegheny Lud.	.040	36	3294
AM-357	*CRT (300,000 Y.S.)	Allegheny Lud.	.060	36	3294
AM-357	*SCCRT (300,000 Y.S.)	Allegheny Lud.	.040	36	3294
AM-357	*SCCRT (300,000 Y.S.)	Allegheny Lud.	.060	36	3294

TABLE 2 (Continued)

MATERIALS ORDERED FOR EVALUATION

Material	Condition	Supplier	Thickness	Min. Sq. Ft.	Budd Purchase Order Number
AM-359	Annealed	Allegheny Lud.	.060	90	3293
AM-359	Annealed	Allegheny Lud.	.125	80	3293
AM-359	Annealed	Allegheny Lud.	.250	30	3293
JLD-300	*CR (300,000 Y.S.)	J & L	.040 X 12"	40	3345
JLS-300	*CR (300,000 Y.S.)	J & L	.060 X 12"	40	3345
JLS-300	*CR (300,000 Y.S.)	J & L	.040 X 6½"	20	3345
JLS-300	*CR (300,000 Y.S.)	J & L	.060 X 7½"	20	3345

*CRT - Cold Rolled and Tempered

*SCCRT - Sub-zero Cooled - Cold Rolled - Tempered

*CR - Cold Rolled

TABLE 2 (Continued)

The material evaluation was broken down into several areas of investigation. Effect of cold reduction, heat treatment or other processing on properties was evaluated. Where tensile property results are below minimums deemed necessary for case design, no further testing was done on the alloy.

Evaluation of the alloys included:

1. Metallurgical Testing.
    - (a) Uniaxial tensile tests.
    - (b) Center notch fracture energy tests.
    - (c) Bend test - longitudinal and transverse.
    - (d) Hardness measurement.
    - (e) Photomicrographic investigation
    - (f) Corrosion tests - specimen stressed in various corrosive environments.
    - (g) Dimensional change specimens.

2. Resistance Welding.
    - (a) Shear tensile specimens.
    - (b) Photomacrographic and hardness traverses.
    - (c) Tension tests - where material properties permitted.

3. Fusion Welding.
    - (a) Tensile Tests.
    - (b) Photomacrographic and hardness traverses.
    - (c) Bend test.
    - (d) Nondestructive tests - X-Ray and penetrant

examination.

4. Heat Treatment Cleaning.

   (a) Effect on properties of various heat treat times and temperatures.

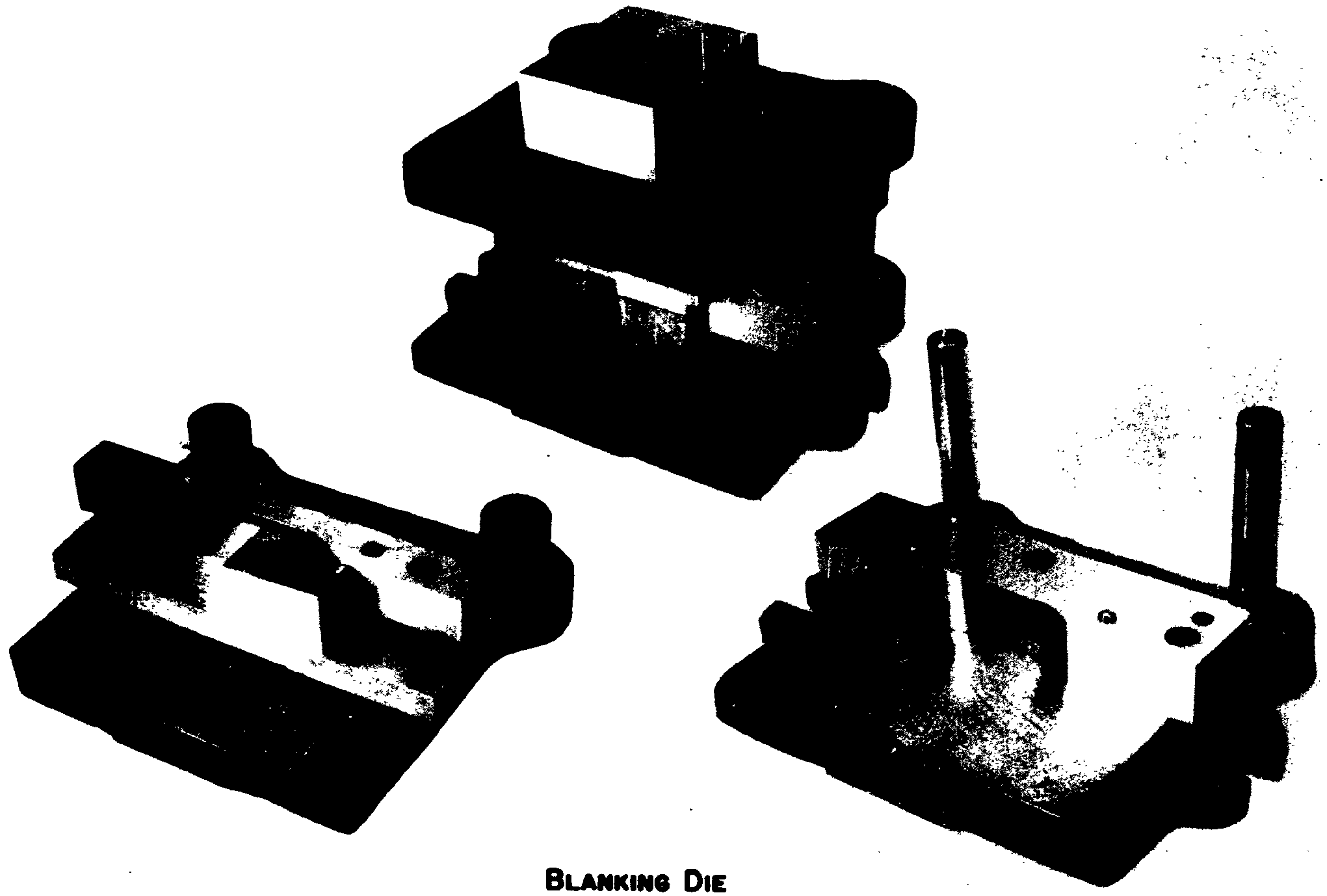
   (b) Cleaning procedures (preweld cleaning).

In the evaluation of the tensile properties of high strength alloys in thin sheet or strip form, rigid test methods are required. The harder, stronger and less ductile materials are more sensitive to misalignment, surface preparation and fillet radii. In order to make an accurate study of the mechanical properties special machining and testing fixtures were designed to permit fabrication of specimens to extremely close tolerances in order to minimize variations due to human element. Figures 1, 2, 3 and 4 are typical fixtures used in the manufacture and testing of specimens.

The specimen selected for tensile testing of high strength sheet alloy has been designed to most effectively accomplish the purpose of representing the true uniaxial behavior of the material. Attempts were made to keep nonuniform loads and bending stresses to the absolute minimum. Typical tensile specimens are shown in Figures 5 and 6. Table 3 is a list of all test specimen drawings and the code designation used in the evaluation.

Table 4 is a description of the coding system used throughout the materials evaluation program and in data tabulations.

In this report it is planned to briefly discuss each of the alloys evaluated and reference the monthly or quarterly report wherein

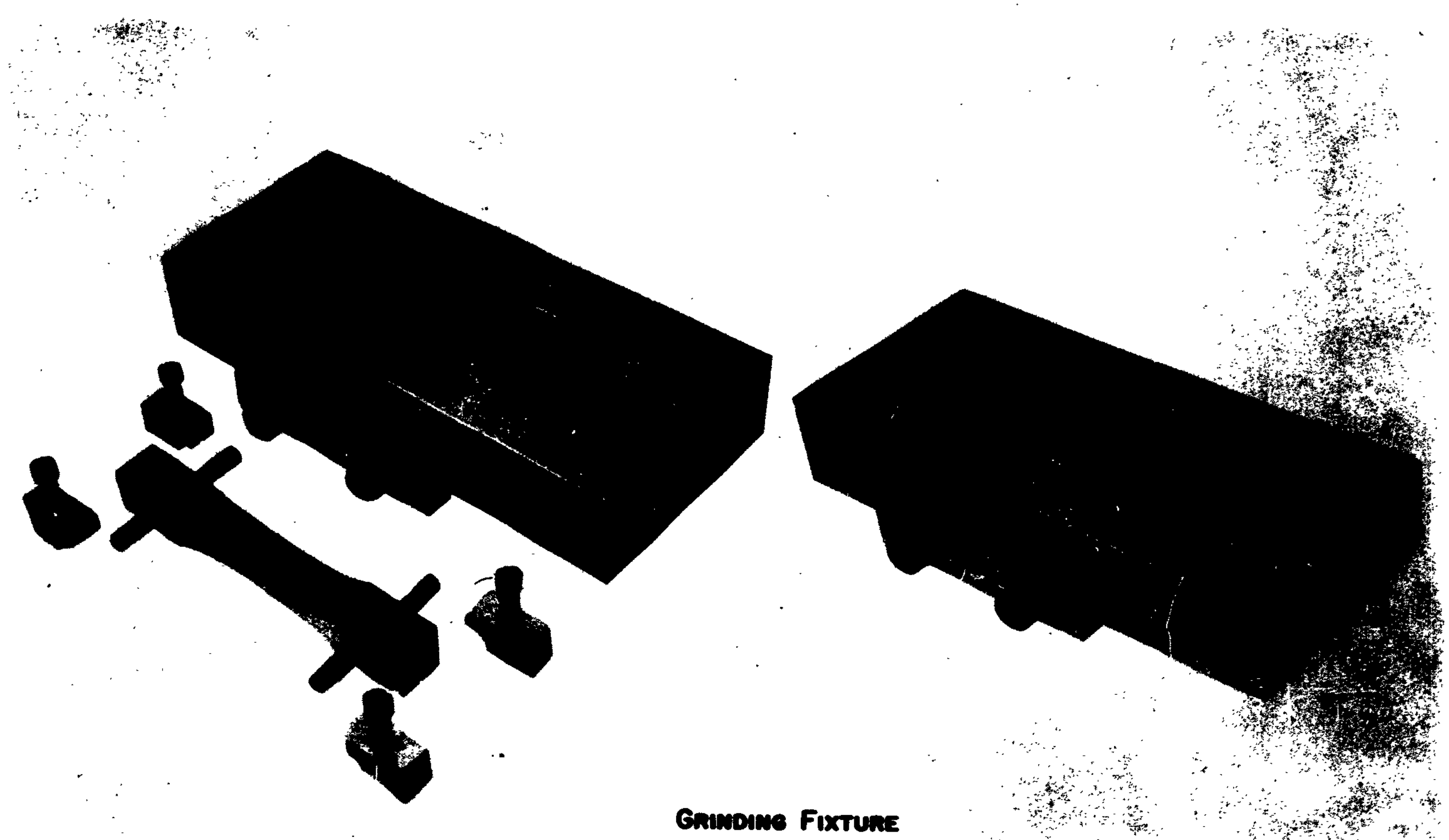


BLANKING DIE
TENSILE SPECIMENS A,C & D

Figure 1

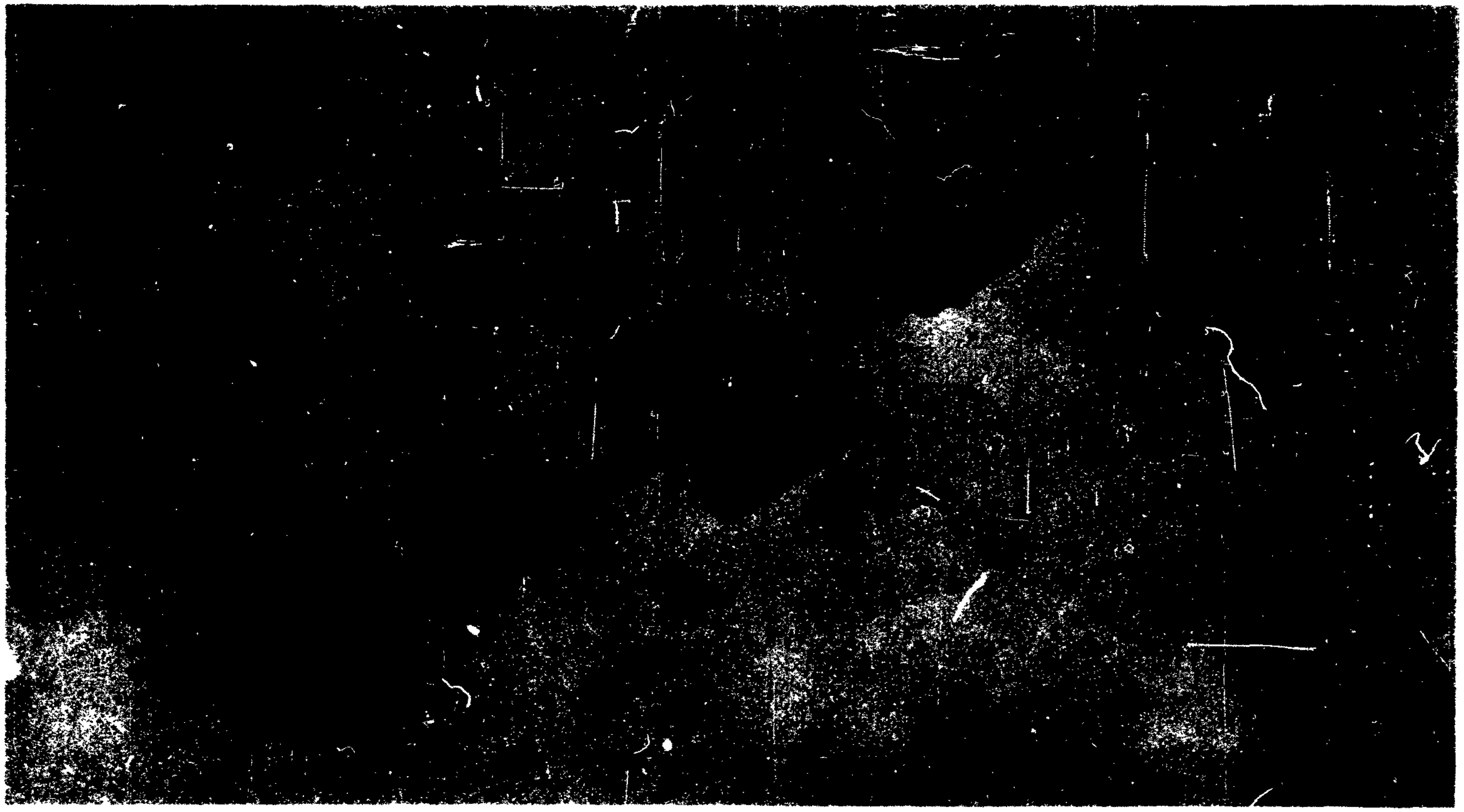
DRILLING FIXTURE
SPECIMENS A C & D

Figure 2



GRINDING FIXTURE
SPECIMENS A,C & D

Figure 3



PIN & CLEVIS ASSEMBLY
SPECIMENS A C & D

Figure 4

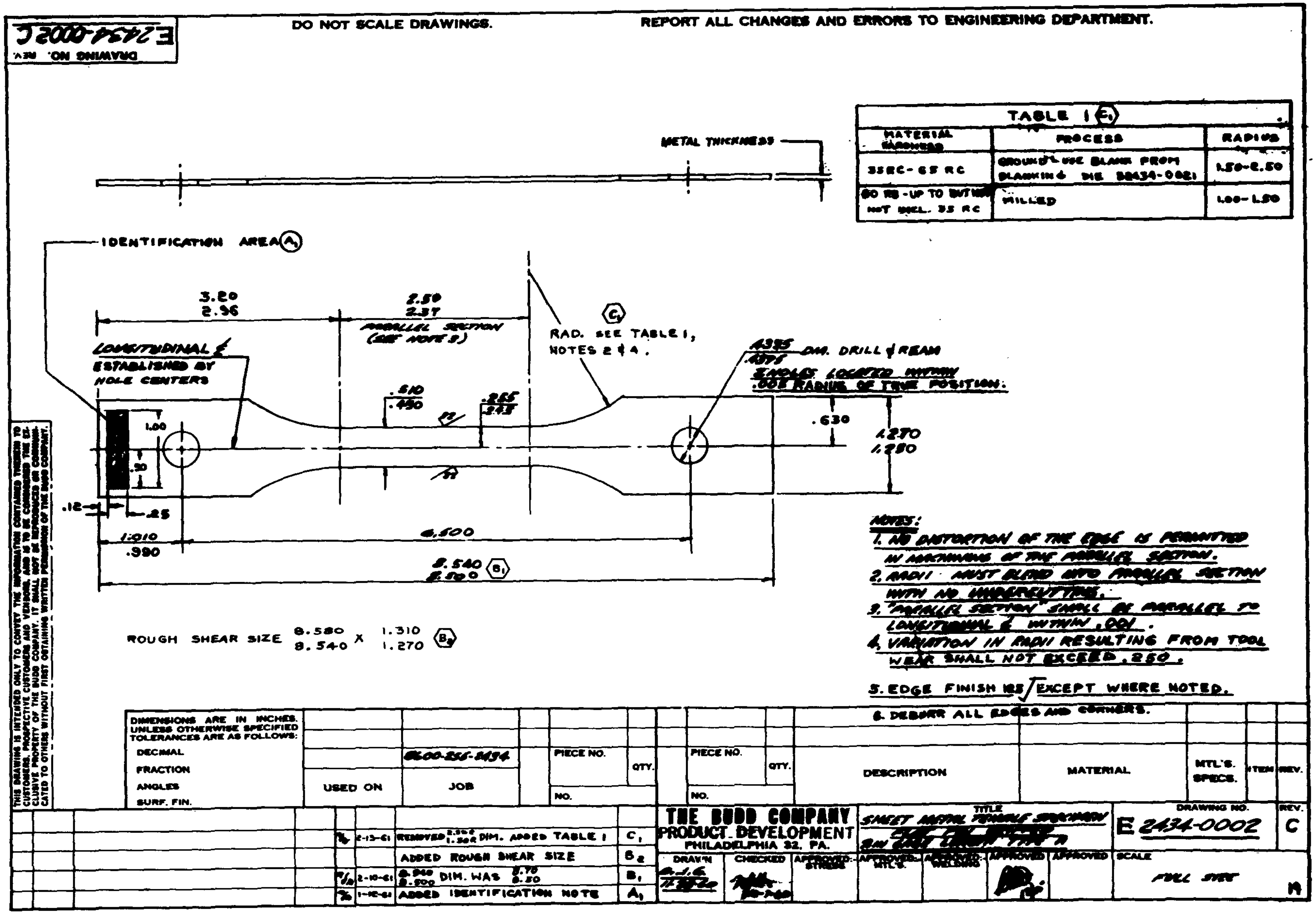
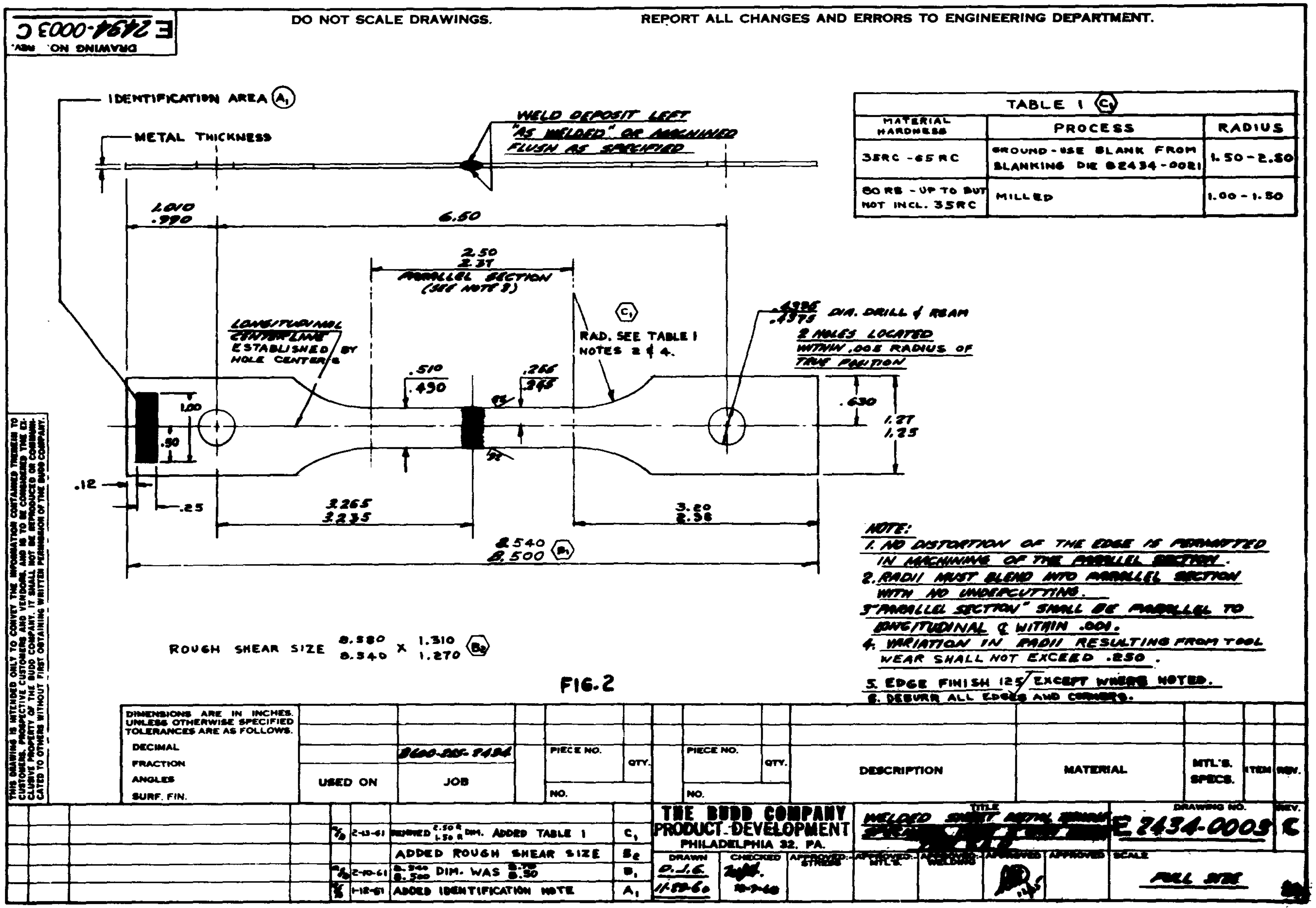

DO NOT SCALE DRAWINGS.
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT.
DRAWING NO. REV.
E 2434-0002 C
METAL THICKNESS
TABLE 1 (C1)
MATERIAL HARDNESS
PROCESS
RADIUS
35RC-65 RC
GROUND-THE BLANK FROM BLANKING DIE 2434-0021
1.50-2.50
MILLED
1.00-1.50
IDENTIFICATION AREA (A1)
3.20
2.96
2.50
2.37
PARALLEL SECTION (SEE NOTE 3)
RAD. SEE TABLE 1, NOTES 2 & 4.
LONGITUDINAL ℄ ESTABLISHED BY HOLE CENTERS
DIA. DRILL & REAM
.510
.490
.630
1.270
1.250
1.00
.50
.12
.25
1.010
.990
6.500
8.540 (B1)
8.500
ROUGH SHEAR SIZE 8.580 X 1.310
8.540 X 1.270 (B2)
NOTES:
1. NO DISTORTION OF THE EDGE IS PERMITTED IN MACHINING OF THE PARALLEL SECTION.
2. RADII MUST BLEND INTO PARALLEL SECTION WITH NO UNDERCUTTING.
3. "PARALLEL SECTION" SHALL BE PARALLEL TO LONGITUDINAL ℄ WITHIN .001.
4. VARIATION IN RADII RESULTING FROM TOOL WEAR SHALL NOT EXCEED .250.
5. EDGE FINISH EXCEPT WHERE NOTED.
6. DEBURR ALL EDGES AND CORNERS.
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED TOLERANCES ARE AS FOLLOWS:
DECIMAL
FRACTION
ANGLES
SURF. FIN.
USED ON
JOB
PIECE NO.
QTY.
NO.
DESCRIPTION
MATERIAL
MTL'S. SPECS.
ITEM
REV.
ADDED ROUGH SHEAR SIZE
DIM. WAS
ADDED IDENTIFICATION NOTE
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.
TITLE
SHEET METAL TENSILE SPECIMEN
DRAWING NO.
E 2434-0002
DRAWN
CHECKED
APPROVED
SCALE
FULL SIZE
Form 8018

Figure 5



DO NOT SCALE DRAWINGS.
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT.
DRAWING NO. REV.
E 2434-0003 C
IDENTIFICATION AREA A1
METAL THICKNESS
WELD DEPOSIT LEFT "AS WELDED" OR MACHINED FLUSH AS SPECIFIED
TABLE I C1
MATERIAL HARDNESS
PROCESS
RADIUS
35RC -65RC
GROUND-USE BLANK FROM BLANKING DIE B2434-0021
1.50-2.50
80 RB - UP TO BUT NOT INCL. 35RC
MILLED
1.00-1.50
1.010
.990
6.50
2.50
2.37
PARALLEL SECTION (SEE NOTE 3)
LONGITUDINAL CENTERLINE ESTABLISHED BY HOLE CENTERS
RAD. SEE TABLE I NOTES 2 & 4.
C1
DIA. DRILL & REAM
2 HOLES LOCATED WITHIN .005 RADIUS OF TRUE POSITION
.510
.490
.266
.630
1.27
1.25
1.00
.50
.12
.25
3.265
3.235
3.20
2.58
8.540
8.500
B1
ROUGH SHEAR SIZE 8.580 / 8.540 X 1.310 / 1.270 B2
FIG. 2
NOTE:
1. NO DISTORTION OF THE EDGE IS PERMITTED IN MACHINING OF THE PARALLEL SECTION.
2. RADII MUST BLEND INTO PARALLEL SECTION WITH NO UNDERCUTTING.
3. "PARALLEL SECTION" SHALL BE PARALLEL TO LONGITUDINAL ℄ WITHIN .001.
4. VARIATION IN RADII RESULTING FROM TOOL WEAR SHALL NOT EXCEED .250.
5. EDGE FINISH 125 EXCEPT WHERE NOTED.
6. DEBURR ALL EDGES AND CORNERS.
DIMENSIONS ARE IN INCHES. UNLESS OTHERWISE SPECIFIED TOLERANCES ARE AS FOLLOWS.
DECIMAL
FRACTION
ANGLES
SURF. FIN.
USED ON
JOB
PIECE NO.
QTY.
NO.
DESCRIPTION
MATERIAL
MTL'S. SPECS.
ITEM
REV.
ADDED TABLE I
C1
ADDED ROUGH SHEAR SIZE
B2
DIM. WAS
B1
ADDED IDENTIFICATION NOTE
A1
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.
DRAWN
CHECKED
APPROVED
TITLE
WELDED
DRAWING NO.
E 2434-0003
REV.
C
SCALE
FULL SIZE
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Figure 6

MATERIAL EVALUATION TEST SPECIMENS - DRAWING LIST

Drawing Number	Description	Code Type
E2434-0002	Tensile Specimen	A
E2434-0014	Tensile-Center Notch Fracture Energy	B
E2434-0003	Tensile-Fusion Weld (As Welded Condition)	C
E2434-0003	Tensile-Fusion Weld-Machined Flush	D
E2434-0004	Tensile Shear-Resistance Spot Weld	E
E2434-0006	Tensile-Resistance Spot Weld-"U" Bend	F
E2434-0007	Bend	G
E2434-0010	Bend-Fusion Welded	H
E2434-0013	Stress Corrosion-Base Metal	J
E2434-0011	Stress Corrosion-Resistance Welded	K
E2434-0008	Dimensional Change	L
E2434-0009	Fusion Welded Plates	M
No Drawing	Photomicrographic Mounts	N
No Drawing	Photomicrographic Mounts-Welds	O
E2434-0002	Tensile-Cleaning (same as Type A)	P
E2434-0012	Tensile-Resistance Weld-Cross	S
E2434-0005	Location-Fusion Weld Specimens-in Plates Type M	-

TABLE 3

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SPECIMEN IDENTIFICATION

Specimen number consists of a four letter group and one digit. The sequence is as follows:

Material Condition Specimen Type. Direction Number in Group

Materials	Code Letter
AM-357	A
AM-359	B
25% Ni	C
20% Ni	D
Ti 13V-11Cr-3Al	E
JLS-300	F
25% Ni (Modified)	G
20% Ni (Modified)	H
Armco 12-8-6	K
Ti 6Al-6V-2Sn	L
Ti 8Al-10V	M

Specimen Type	Code Letter
Sheet Tensile	A
Fracture Energy, Center Notch	B
Sheet Tensile, "As Welded"	C
Sheet Tensile, Weld Deposit Removed	D
Tensile Shear, Resist Weld	E
Tensile, Resist Weld, "U" Bend	F
Bend Specimen, Base Metal	G
Bend Specimen, Welded, Weld Deposit Removed	H
Stress Corrosion, Resist Weld	K
Dimensional Change Specimen	L
Arc Welding Plates	M
Photomicrographic Mounts	N
Photomicrographic Mounts	O
Tensile Specimens, Cleaning	P
Tensile, Resist Weld, Crisscross	S

Conditions	
Annealed	A
SCCRT	B
CRT	C
SCT	E
Ti, Single Age	F
Ti, Double Age	G
C. W. 200,000	J
C. W. 230,000	K
25% Ni, Heat Treated	L
20% Ni, Heat Treated	M
Cold Rolled ≠ Aged	N
12-8-6, Heat Treated	P

Direction

Indicated as L (longitudinal) or T (transverse)

TABLE 4

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a more detailed discussion may be found. A summary of typical data will also be included in this report for each alloy evaluated.

The chemical compositions of the alloys, including welding wires, selected for evaluation, are shown in Table 5.

20% and 25% Nickel Mar-aging Steels (Ref. Report Nos. 4, 9, 11, 18 and 21)

Two of the most interesting high strength alloys developed in recent years are the 20% nickel and 25% nickel steels. These alloys were developed at the International Nickel Company's Bayonne Research Laboratory. Both alloys have the capability of attaining yield strengths of 300,000 psi or greater, based on the composition and heat treatments employed during processing.

Some typical physical properties of the alloys are summarized below:

Density	- 0.286 lb./in.^{3}
Linear coefficient of expansion	- 6.3 X 10^{-6} in./in./$^\circ$F. Room temperature to 800°F.
Modulus of elasticity	- 25.0 X 10^6 PSI
Poisson's ratio	- μ = 0.31
Melting range	- 2650°F - 2750°F

The 20% and 25% nickel steels have similar hardening mechanisms. The chief hardening constituent is titanium, with aluminum and columbium being added for other effects. The 20% nickel steel is martensitic at room temperature and cannot be annealed to below 30 to 35 Rockwell C hardness.

C H E M I C A L   C O M P O S I T I O N

A L L O Y S   E V A L U A T E D   F O R   R O C K E T   C A S E   A P P L I C A T I O N

Alloy	Designation	C	Mn	P	S	Si	Cr	Ni	Mo	Al	V	Cb	Ti	Fe	B	Zr	Sn	Cu	N_2	O_2	H_2	
		COMPOSITION - PERCENT BY WEIGHT																				
20% Ni	Heat 23222-1 (Std. Analysis)	0.007	0.105	0.007	0.002	0.15	-	20.04	-	0.22	-	0.52	1.27	Bal.	-	-	-	-	-	-	-	Allegheny Ludlum Steel Corp.
20% Ni	Heat 23579-1 (Hi-Ti Modified)	0.019	0.010	0.002	0.002	0.010	-	19.96	-	0.50	-	0.60	1.72	Bal.	0.004	0.019	-	-	-	-	-	Allegheny Ludlum Steel Corp.
25% Ni	Heat 23223-3 (Std. Analysis)	0.006	0.12	0.008	0.002	0.17	-	25.33	-	0.20	-	0.54	1.37	Bal.	-	-	-	-	-	-	-	Allegheny Ludlum Steel Corp.
25% Ni	Heat 23569-1 (Hi-Ti Modified)	0.018	0.010	0.001	0.001	0.010	-	25.18	-	0.50	-	0.60	1.72	Bal.	0.004	0.015	-	-	-	-	-	Allegheny Ludlum Steel Corp.
AM-357	Heat 22902	0.24	0.79	0.022	0.015	0.17	14.00	4.40	2.74	-	-	-	-	Bal.	-	-	-	-	-	-	-	Allegheny Ludlum Steel Corp.
AM-359	Heat 23338-1B	0.20	0.66	0.021	0.017	0.39	14.34	7.13	2.52	1.00	-	-	-	Bal.	-	-	-	-	-	-	-	Allegheny Ludlum Steel Corp.
Ti 6-6-2	Heat 29536	0.02	-	-	-	-	-	-	-	5.73	5.38	-	-	0.08	-	-	2.30	0.75	0.014	0.137	-	Reactive Metals
Ti 13-11-3	Heat M9584 Typ.	0.019	-	-	-	-	10.6	-	-	2.8	13.5	-	-	0.16	-	-	-	-	0.025	0.131	0.013	Titanium Metals Corp.
PH 12-8-6	Heat V031042	0.07	0.50	0.025	0.015	0.40	11.50	8.0	6.0	1.15	-	-	-	Bal.	-	-	-	-	-	-	-	Armco Steel Corp.
JLS 300	Heat 61616	0.11	1.27	0.02	0.013	0.69	17.20	5.12	0.16	-	-	-	-	Bal.	-	-	-	0.15	0.08	-	-	Jones & Laughlin Steel Corp.
20% Ni	Heat 24022 (20" Case Matl.)	0.008	0.008	0.004	0.005	0.019	-	19.97	-	0.47	-	0.42	1.85	Bal.	0.001	0.018	-	-	-	-	-	Allegheny Ludlum Steel Corp.
20% Ni Weld Wire	7C088 A.L.	0.029	0.003	0.008	0.007	0.005	0.006	19.72	-	0.26	-	0.43	1.62	Bal.	-	-	-	-	-	-	-	Allegheny Ludlum Steel Corp.
20% Ni Weld Wire	V-00695	0.003	0.01	0.001	0.003	0.02	-	20.35	-	0.42	-	0.47	1.68	Bal.	0.002	0.02	-	-	-	-	-	Carpenter Steel Company

Table 5

The 25% nickel steel has a more stable analysis. The M_s temperature is below room temperature, therefore, the alloy remains austenitic at room temperature after anneal at 1500°F.

Two heats of both the 20% and 25% alloy were evaluated during the program Both heats were furnished by Allegheny-Ludlum Steel Corporation. The chemical compositions of these heats are shown in Table 5.

25% Nickel Mar-aging Steel (Heat Nos. 23223-3 & 23569-1)

The first evaluation of this alloy, Allegheny-Ludlum Heat No. 23223-3, was air induction melted, followed by consumable electrode vacuum remelt. The .060 sheet material was received in the annealed condition.

A summary of the mechanical properties are shown in Table 6. The material was tested in the re-annealed condition and various heat treated conditions.

The heat exhibited reasonably high ultimate strength values. However, the yield strengths were low. Data from other investigators indicated a higher yield to ultimate strength ratio. The sheet material also indicated a large difference between longitudinal and transverse ductility. This is attributed to a badly segregated structure which aggravated the anisotropic condition usually associated with sheet product. Photomacrographs made of annealed

MECHANICAL PROPERTIES OF 25% NICKEL STEEL
TYPICAL VALUES FROM EVALUATION PROGRAM

Heat Number	Gage	Condition	L or T	.2% Yield Strength KSI	Tensile Strength KSI	% Elong. in 2"	Hard-ness	Fracture Toughness K_{c1}	Fracture Toughness G_c	Remarks
Allegheny		Annealed 1500°F 15 min.	L	56	125	22.5	B92	-	-	Av.4 Tests ea.
			T	52	122	25	B92	-	-	
Ludlum	.060	Heat Treated 1100°F 16 hrs.; -100°F 16 hrs.; 800°F 1 hr.	L	232	296	7	C56	-	-	" " " "
			T	240	295	2	C56	-	-	
23223-3		Heat Treated 1200°F 8 hrs.; -100°F 16 hrs.; 800°F 1 hr.; -100°F 16 hrs.; 850°F 1 hr.	L	245	258	6	C53	-	-	" " " "
			T	250	264	6	C53	-	-	
Allegheny	.075	Mill Annealed	L	84	118	36	B97	-	-	Av. 4 Spec.
			T	92	116	32	B97	-	-	
	.125	Mill Annealed	L	66	113	34	B97	-	-	
			T	83	113	31	B97	-	-	
Ludlum	.125	1100°F 16 hrs.; -100°F 16 hrs.; 800°F 1 hr.	L	145	250	3	C50	-	-	Av. 4 Spec.
			T	153	241	2	C50	-	-	
23569-1		1200°F 8 hrs.; -100°F 16 hrs.; 800°F 1 hr.; -100°F 16 hrs.; 850°F 1 hr.	L	All specimens broke without reaching				-	-	3L & 3T
			T	yield point - very brittle fracture				-	-	

TABLE 6 (Continued)

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MECHANICAL PROPERTIES OF 25% NICKEL STEEL
TYPICAL VALUES FROM EVALUATION PROGRAM

Heat Number	Gage	Condition	L or T	.2% Yield Strength KSI	Tensile Strength KSI	% Elong. in 2"	Hard-ness	Fracture Toughness K_{c1}	G_c	Remarks
Allegheny	.125	1200°F 8 hrs. -100°F 16 hrs. 900°F 2 hrs.	L	293	342	2	C59	-	-	Av. 4 Specs.
			T	305	356	1.5		-	-	Av. 4 Specs.
		1600°F Anneal 1150°F 8 hrs. -100°F 16 hrs. 850°F 2 hrs.	L	182	290	2	C56	-	-	Av. 3 Specs.
			T	190	290	2.5	C56	-	-	Av. 3 Specs.
Ludlum	.075	1200°F 8 hrs. -100°F 16 hrs. 900°F 2 hrs.	L	210	285	3	R_c58	23,000	68	Av. 4 Specs.
			T	238	310	3	R_c58	23,000	68	Av. 4 Specs.
		1200°F 8 hrs. -100°F 16 hrs. 900°F 2 hrs. -100°F 16 hrs. 950°F 2 hrs.	L	220	300	6	R_c56	31,000	75	Av. 4 Specs.
			T	245	315	8	R_c56	33,000	75	Av. 4 Specs.
23569-1		Cold Rolled 65% Red. -100°F 16 hrs. 850°F 3 hrs.	L	275	304	3	R_c58	52,000	100	Av. 4 Specs.
			T	306	330	2	R_c58	-	-	Av. 4 Specs.

TABLE 6 (Continued)

material showed evidence of a banded structure due to segregation. The bands may be a complex titanium compound or layers of retained austenite. This condition was believed to have a definite effect on the longitudinal and transverse properties. The modulus of elasticity was also low for the alloy, being approximately 20 X 10^6 psi compared to an expected value in the area of 25 X 10^6 psi.

It was decided to terminate testing of this heat and secure an additional heat of the alloy to complete the evaluation.

A second heat of 25% nickel was obtained from Allegheny-Ludlum Steel Corporation for evaluation. The composition of this heat, No. 23569-1, is also shown in Table 5. It contains higher amount of titanium and aluminum in accordance with recommendation of International Nickel Company Laboratories. This heat was vacuum primary melted and the remelt was by the vacuum consumable electrode process. High purity iron and other alloys were employed in this heat.

The mechanical properties of the heat, No. 23569-1, are summarized in Table 6. Annealed properties and effect on properties of various heat treatments are shown.

Two heat treatments were employed on .125 inch thick material:

1. Material in 1500°F annealed condition; aus-age at 1200°F, 8 hours; air cool; cool at -100°F, 16 hours; air warm; mar-age at 900°F, 2 hours; air cool.

2. Anneal at 1600°F 15 minutes; air cool; aus-age at 1150°F, 8 hours; air cool; cool at -100°F, 16 hours; air warm; mar-age at 850°F, 2 hours.

The first treatment produced uniformly high strength even with the use of a higher mar-aging temperature. The second treatment resulted in lower strength values, probably due to the excessive retention of austenite. Complete transformation may have been hampered by the 1600°F anneal or by failure of the aus-aging to properly unstablize the austenite in the time allowed.

Heat treatment of the .075 specimens was modified slightly, employing a double sub-zero cool and mar-aging cycle. Resulting properties are shown in Table 6. Full property capability of the alloy was not obtained. Values were actually lower than expected. Again, retained austenite is suspected as the cause for the large spread between yield and ultimate strengths.

Tensile and center notch fracture toughness specimens were prepared and tested. Results are summarized in Table 6. Cold reduction adds very little to the strength proper-

ties of this alloy. The alloy exhibits little cold work or strain hardening characteristics.

No additional testing was done on the 25% alloy because of our decision to concentrate effort on the 20% grade.

20% Nickel Mar-aging Steel (Ref. Nos. 4, 9, 11, 18 and 21)

Two heats, Allegheny-Ludlum Nos. 23222-1 and 23579-1, of 20% nickel steel were evaluated. Both heats were produced by Allegheny-Ludlum Steel Corporation. Chemical compositions are summarized in Table 5.

The first testing was done, using .060 thick annealed sheet from heat No. 23222-1 and mechanical properties are shown in Table 7.

This alloy is martensitic in the annealed condition and results confirmed the relatively high strength and low ductility expected. Hardness of R_c 33 in the annealed condition was as expected.

The standard -100°F, 3 hours; aging at 850°F, 1 hour treatment resulted in values lower than anticipated for this alloy. Ultimate strengths were low and erratic.

A double aging isothermal treatment was used and much higher yield and ultimate strengths were obtained with fair ductility.

In general, results from this heat were not consistent

MECHANICAL PROPERTIES OF 20% NICKEL STEEL
TYPICAL VALUES FROM EVALUATION PROGRAM

Heat Number	Gage	Condition	L or T	.2% Yield Strength KSI	Tensile Strength KSI	% Elong. in 2"	Hard- ness	Fracture K_{c1}	Fracture G_c	Remarks
		Annealed	L	101	148	7	C33	-	-	Av. 4 Specs.
Allegheny		1500°F 15 min.	T	107	149	6	C33	-	-	Av. 4 Specs.
		-100°F 16 hrs.	L	209	222	8	C48	-	-	Av. 4 Specs.
		850°F 1 hr.	T	240	258	1.5	C52	-	-	Av. 4 Specs.
Ludlum	.060									
		1500°F 15 min.	L	270	295	1.5	C55	-	-	Av. 4 Specs.
		Cool to 1100°F								
		1100°F 16 hrs.								
23222-1		-100°F 16 hrs.								
		850°F 1 hr.	T	268	275	1.0	C55	-	-	Av. 4 Specs.
		-100°F 16 hrs.	L	300	310	1.5	C55	-	-	Av. 4 Specs.
Allegheny		900°F 2 hrs.	T	308	318	0.5	C55	-	-	Av. 4 Specs.
		1500°F 15 min.	L	304	335	4.0	C60	-	-	Av. 3 Specs.
		Cool to 1150°F								
	.125	1150°F 8 hrs.								
		-100°F 16 hrs.								
Ludlum		950°F 2 hrs.	T	312	353	3.0	C60	-	-	Av. 3 Specs.
		Mill Annealed	L	128	172	9.5	C41	-	-	Av. 4 Specs.
			T	136	180	7.5	C41	-	-	Av. 4 Specs.
		Mill Annealed	L	121	194	8.0	C41	-	-	Av. 4 Specs.
			T	123	204	7.5	C41	-	-	Av. 4 Specs.
23579-1	.075									
		-100°F 16 hrs.	L	326	335	3.0	C57	38,000	-	Av. 4 Specs.
			T	340	350	1.5	C57	37,000	-	Av. 4 Specs.

TABLE 7 (Continued)

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MECHANICAL PROPERTIES OF 20% NICKEL STEEL
TYPICAL VALUES FROM EVALUATION PROGRAM

Heat Number	Gage	Condition	L or T	.2% Yield Strength KSI	Tensile Strength KSI	% Elong. in 2"	Hard-ness	Fracture K_{c1}	Fracture G_c	Remarks
Allegheny	.075	1500°F 15 min. Furn. Cool to 1150°F	L	315	321	3	C56	54,500	-	Av. 4 Specs.
		1150°F 8 hrs. -100°F 16 hrs. 950°F 2 hrs.	T	335	344	2	C56	49,200	-	Av. 4 Specs.
Ludlum		Cold Rolled 65% Red.	L	328	330	2.0	C58	57,000	-	Av. 4 Specs.
		-100°F 16 hrs. 850°F 3 hrs.	T	340	362	-	C58	33,000	-	Av. 4 Specs.
23579-1	.033	Cold Rolled 65% Red.	L	345	358	1.5	C60	45,000	-	Av. 4 Specs.
		-100°F 16 hrs. 850°F 3 hrs.	T	376	386	Nil	C60	24,500	-	Av. 4 Specs.

TABLE 7 (Continued)

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and since a new all-vacuum melted heat was being ordered, no additional testing was done on material from heat No. 23222-1.

The second heat, No. 23579-1, produced by Allegheny-Ludlum Steel Corporation, was made to a composition suggested by International Nickel Company. The modification consisted mainly of an increase in hardner elements, titanium, aluminum and columbium. The composition is shown in Table 5.

The heat was vacuum primary melted and consutrode electrode vacuum remelted. Sheet material .125 and .075 inchés thick was obtained in the annealed condition and .075 and .033 inches thick sheet was cold rolled 65% to final gage.

Heat treat procedures were established using the 0.125 inch thick annealed material. Two treatments were selected initially to obtain maximum strength response:

A. 1. Material in the 1500°F annealed condition.
   2. Cool at -100°F, 16 hours minimum; air warm.
   3. Mar-age at 850°F, 1 hour; air cool.

B. 1. Re-anneal at 1500°F, 15 minutes; cool in furnace to 1100°F, 8 hours; air cool.
   2. Cool at -100°F, 16 hours minimum; air warm.
   3. Mar-age at 850°F, 1 hour; air cool.

Tensile test results of the 0.125 inch thick material after the above heat treatments showed that the material was in a very high strength condition and low toughness. Difficulty was experienced in handling the specimens during test. Failures were experienced outside the gage length and they exhibited no yielding prior to fracture.

The heat treatments were altered to obtain lower yield strengths in the area of 300,000 to 310,000 psi. The following heat treatments were used:

A. 1. Material in 1500°F annealed condition.
   2. Cool at -100°F, 16 hours minimum; air warm.
   3. Mar-age at 900°F, 1 hour; air cool.

B. 1. Re-anneal at 1500°F, 15 minutes; cool in furnace to 1150°F, 8 hours; air warm.
   2. Cool at -100°F, 16 hours minimum; air warm.
   3. Mar-age at 950°F, 2 hours; air cool.

The response to these treatments was more satisfactory, showing greater ductility at high strength. Using these treatments, tensile and fracture toughness specimens were made and tested. In the 0.075 inch thickness, both the straight aging and isothermal treatment developed yield strengths of 300,000 psi plus. Fracture toughness was improved on isothermally treated specimens.

Specimens were made from 0.032 inch thick material which had been cold reduced 65% to final gage. Aging temperature of 850°F for three hours was used. In the lighter gage, the tensile strengths were higher but fracture toughness and ductility was somewhat lower.

In order to more fully understand the effect of aging temperature and time on mechanical properties of 20% nickel steel, a testing program was established using the .032 inch thick cold rolled material. Transverse and longitudinal test specimens were aged for three hours at temperatures of 750°F to 1000°F in 50°F increments. Results are shown in graphs Figures 7 and 8. Specimens were also aged at a temperature of 950°F for times of 1, 2 and 4 hours to determine the effect of aging time on properties. Figure 9 shows the results of this series of tests. The fracture toughness, K_c value, is plotted against aging temperatures in Figure 10 and at 950°F for times of 1, 2 and 4 hours are shown in Figure 11.

Based on the data shown, an aging temperature of 950°F was selected for material cold rolled 65% to final gage to attain a yield strength of 305 to 315 ksi with highest possible fracture toughness.

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CHECKED BY:		REPORT NO.
DATE:	LONG. TENSILE STRENGTH VS. AGING TEMP. (3 HOURS)	PROJECT NO.

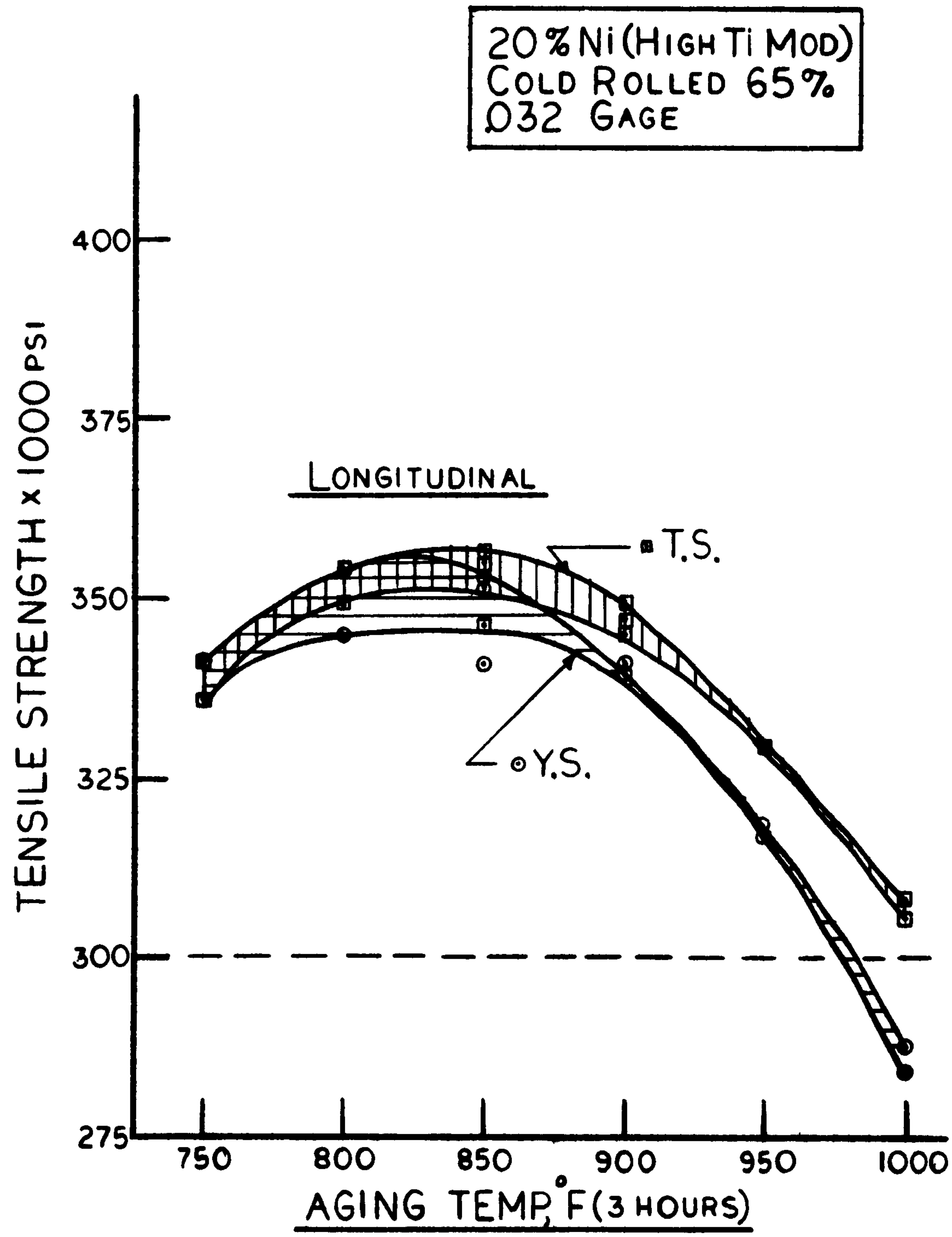

Figure 7

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DATE:	TRANS. TENSILE STRENGTH VS. AGING TEMP. (3 HOURS)	PROJECT NO.

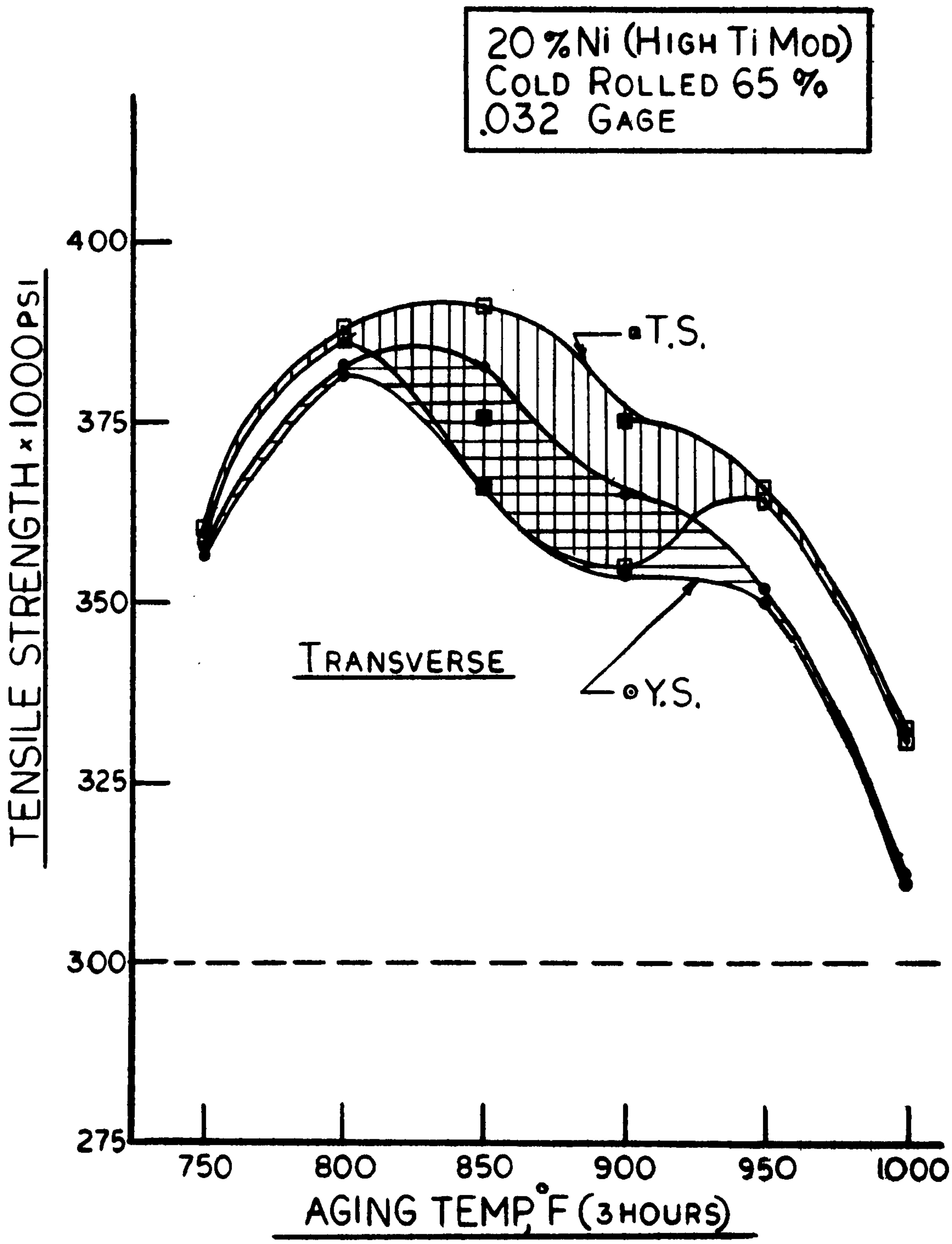

Figure 8

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DATE:	TENSILE STRENGTH VS. AGING TIME @ 950°F	PROJECT NO.

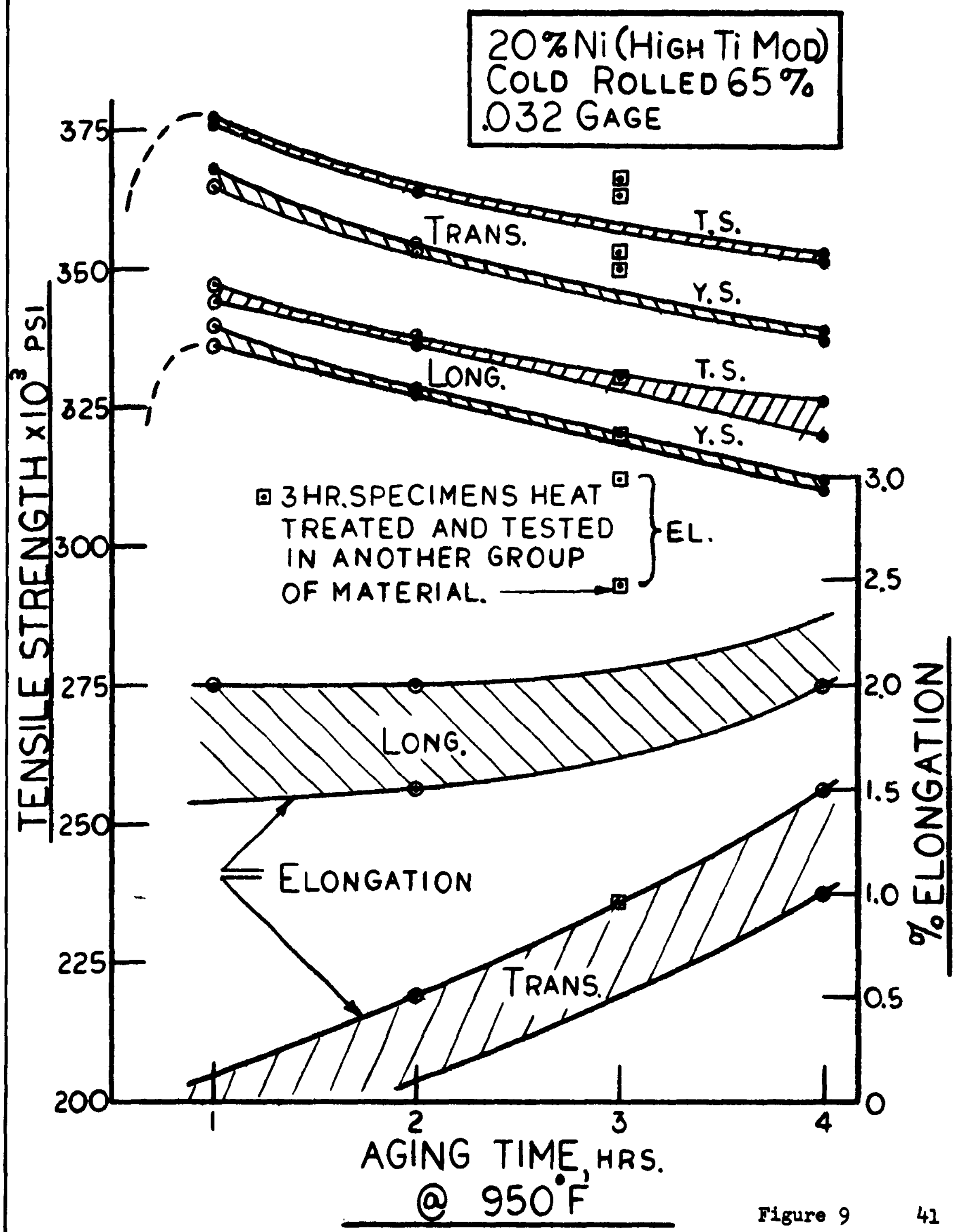

Figure 9

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CHECKED BY:		REPORT NO.
DATE:	K_{C1} VS AGING TEMP. (3 HOURS)	PROJECT NO.

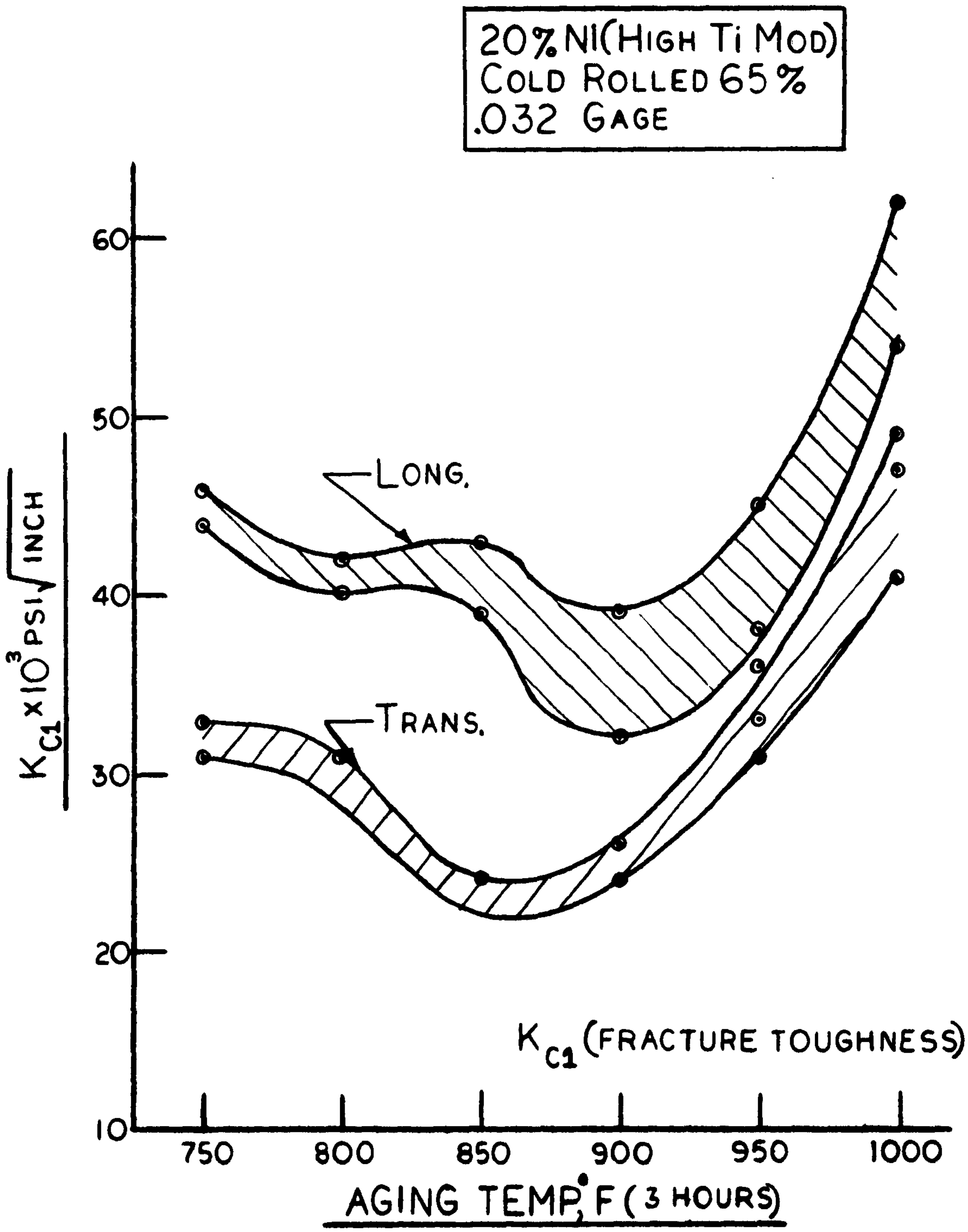

Figure 10

PREPARED BY:	THE BUDD COMPANY PRODUCT DEVELOPMENT PHILADELPHIA, PA.	PAGE NO. OF
CHECKED BY:		REPORT NO.
DATE:	K_{C1} VS. AGING TIME @ 950°F	PROJECT NO.

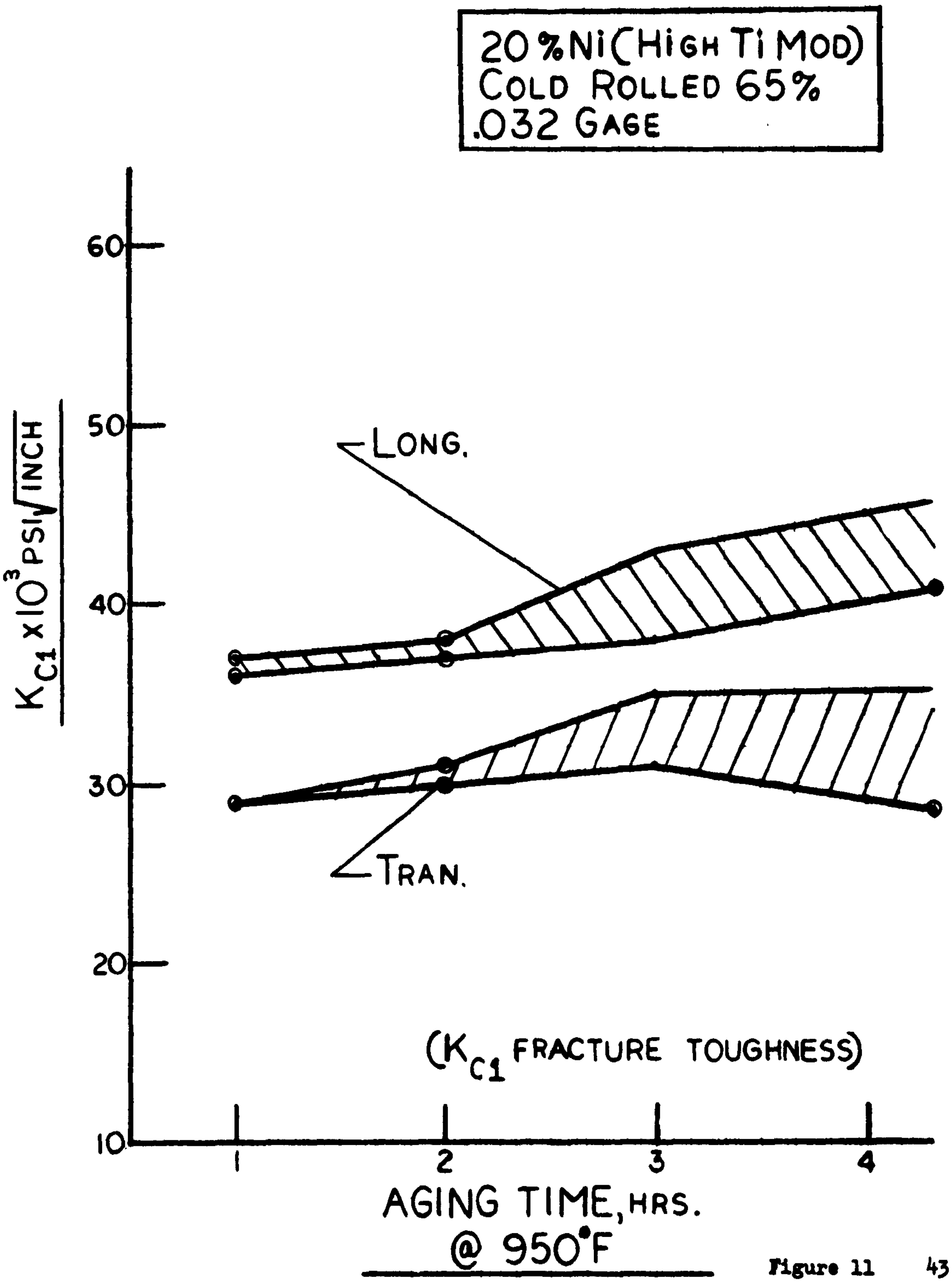

Figure 11

Welding 20% Nickel Mar-aging Steel (Heat No. 23579-1)

An extensive program was initiated to evaluate the welding characteristics of the 20% nickel mar-aging steel. Tungsten inert gas arc welding was used on material from Allegheny-Ludlum heat No. 23579-1 in the following conditions:

0.032 inch - cold rolled 65%.

0.032 inch - cold rolled and aged.

0.075 inch - annealed

0.075 inch - annealed and aged.

Tensile test specimens were taken from 6 inch X 13 inch weldments. The specimens were made in accordance with drawing No. 2434-0003. Matching analysis filler wire was used throughout the evaluation. Evaluation of material in the "as welded" condition and in various post welding heat treatments was made.

The welding schedule found to be most optimum for this alloy is shown in Table 8.

Table 9 summarizes the results of the welding evaluation.

The primary object of the evaluation was to establish an aging treatment which would develop a yield strength in the weld joint of from 190,000 psi to 210,000 psi. This strength range is considered adequate in the design of the rocket case.

T.I.G. WELDING SCHEDULES

MATERIAL: 20% NICKEL STEEL - HIGH TITANIUM COMPOSITION

Gage	Material Condition	Weld Current Amps.	Arc Voltage Volts	Travel Speed In./Min.	Wire Diam. Ins.	Wire Feed In./Min.	Electrode Diam. Ins.	Chill Bar Spacing Ins.
0.032"	Cold Rolled	48-54	8-9	10	1/32	12	1/16	1/4
0.075"	Annealed	100-105	10	$8\frac{1}{2}$	1/32	18	3/32	1/2
0.075"	Mar-Aged 950°F	110	10	$8\frac{1}{2}$	1/32	18	3/32	1/2

Welding Conditions Common to Both Material Conditions and Gages:

1. Weld current is direct current, straight polarity (DCSP).
2. Matching analysis filler wire.
3. Backup plate (Dwg. No. 2434-0103), groove 0.050" X 0.250", with gas ports.
4. Metallic nozzle I.D. - 5/8" (#10).
5. 2% thoriated tungsten electrodes dressed to a conical point.
6. Electrode stick-out - 1/2".
7. Copper chill bars.
8. Torch gas - argon at 30 CFH, trail gas - argon at 15 CFH, backup gas - helium at 12 CFH.

TABLE 8

20% NICKEL STEEL
TENSILE PROPERTIES OF T.I.G. ARC WELDS
SUMMARY OF DATA

Heat Number: Base Metal	Heat Number: Filler Wire	Gage	Condition	.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % ½"	Elongation % 1"	Elongation % 2"	Location of Fracture	Remarks
Allegheny Ludlum 23529-1	Carpenter V-00695 (Matching)	.075	Annealed As Welded	121	135	17	8	5	Weld Zone	Av. 3 Specs.
			Annealed As Welded Reinf.Removed	130	142	15	7	4	Weld Zone	Av. 3 Specs.
			Annealed Welded -100°F, 16 hrs. 950°F, 3 hrs.	-	220	2	1	1	H.A.Z.	Av. 4 Specs.
			Annealed Welded -100°F, 16 hrs. 950°F, 3 hrs. Weld Reinf. Removed	-	250	2	1	1	H.A.Z.	Av. 4 Specs.
			Annealed Welded -100°F, 16 hrs. 950°F, 8 hrs.	Low ductility; joint cracked in preparation of tensile specimen.						
			950°F, 3 hrs. Welded	123	125	14	7	4	Weld Zone	Av. 2 Specs.
			Annealed Welded -100°F, 16 hrs. 600°F, 3 hrs.	168	177	11	6	2	H.A.Z.	Av. 2 Specs.

TABLE 9 (Continued)

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20% NICKEL STEEL
TENSILE PROPERTIES OF T.I.G. ARC WELDS
SUMMARY OF DATA

Heat Number										
Base Metal	Filler Wire	Gage	Condition	.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % ½"	1"	2"	Location of Fracture	Remarks
Allegheny Ludlum 23529-1	Carpenter V-00695 (Matching)	.075	950°F, 3 hrs. Welded -100°F, 16 hrs. 600°F, 3 hrs.	173	178	13	7	3.5	H.A.Z.	Av. 2 Specs.
			950°F, 3 hrs. Welded -100°F, 16 hrs. 700°F, 3 hrs.	190	194	12	6	3.5	H.A.Z.	
			950°F, 3 hrs. Welded -100°F, 16 hrs. 900°F, 3 hrs.	-	212	2	1	1	H.A.Z.	
			950°F, 3 hrs. Welded -100°F, 16 hrs. 950°F, 8 hrs.	-	260	2	1	1	H.A.Z.	
		.032	Cold Rolled 65% Welded	-	177	3	1.5	1	H.A.Z.	
			Cold Rolled 65% Welded Remove Reinf.	177	178	5	3	2	H.A.Z.	
			Cold Rolled 65% Welded -100°F, 16 hrs. 600°F, 3 hrs.	-	202	5	2.5	1.5	H.A.Z.	

TABLE 9 (Continued)

The Budd Co.
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20% NICKEL STEEL
TENSILE PROPERTIES OF T.I.G. ARC WELDS
SUMMARY OF DATA

Heat Number: Base Metal	Heat Number: Filler Wire	Gage	Condition	.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % ½"	Elongation % 1"	Elongation % 2"	Location of Fracture	Remarks
Allegheny Ludlum 23579-1	Carpenter V-00695 (Matching)	.032	Cold Rolled 65% Welded -100°F, 16 hrs. 700°F, 3 hrs.	215	216	4	2	1	H.A.Z.	
			Cold Rolled 65% Welded -100°F, 16 hrs. 900°F, 3 hrs.	-	280	1.5	.5	.5	H.A.Z.	
			Cold Rolled 65% Welded -100°F, 16 hrs. 1000°F, 3 hrs.	313	322	3	1.5	1.0	H.A.Z.	
			Cold Rolled 65% Welded -100°F, 16 hrs. 600°F, 3 hrs. 950°F, ½ hr.	-	313	2	1	.5	H.A.Z.	
			Cold Rolled 65% Welded -100°F, 16 hrs. 950°F, 8 hrs.	-	80	1	0.5	0.5	H.A.Z.	

TABLE 9

The Budd Co.
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The "as welded" strength of annealed material was lower than base metal strength and failure occurred in the welded zone of all specimens tested. Refrigeration at -100°F for 16 hours, followed by aging at 950°F, produced varying results with tensile strengths from 171,000 to 256,000 psi, with failures occurring in the heat affected zone. The most consistent results at the strength level of 200,000 psi yield of annealed and aged material were obtained using aging temperatures in the 600°F to 700°F range.

Evaluation of fusion welded joints using .032 thick sheet, which had been cold rolled 65% to final gage, was made. The "as welded" cold rolled material exhibited much higher strengths than annealed and mar-aged material. Again aging in the 600°F to 700°F range produced properties in range desired for the rocket case design. High temperature aging in the range of 900°F to 1000°F produced very high strengths, but ductility was considerably less.

The 20% nickel mar-aging steel for the 20 inch test case was ordered to an analysis similar to the material evaluated. Confirming evaluation of the new heat, including the effect on properties of various aging temperatures, cold reductions and welds were made prior to application of the material to the case.

20% Nickel Mar-aging Steel for 20 Inch Test Cases

Evaluation of Cold Rolled and Aged Strip Allegheny-Ludlum Heat No. 24022

The data from the processing of 0.040 inch strip at various percentages of reduction and at various aging temperatures were published in Report No. 21. This work was done with Allegheny-Ludlum Heat No. 24022, which was ordered for the production of the 20 inch diameter test cases. The material was made to a chemical analysis specified by The Budd Company. The steel was vacuum induction melted and consumable electrode vacuum remelted. The analysis of the material is shown below:

C	Mn	P	S	Si	Ni
.008	.008	.004	.005	.019	19.97

Al	Cb	Ti	Zr	B	Fe
.47	.42	1.85	.018	.001	Bal.

The prior investigation was accomplished using laboratory cold rolled strip. Data shown in this report were obtained with commercially produced sheet and strip from the same heat of steel. The 0.040 inch thick strip was received as 60% cold reduced strip in a 12 inch wide coil for the cylindrical section of the case. The 0.065 inch thick sheet stock was purchased as annealed, 40 inch X 40 inch squares to be used for the deep drawing of the 20 inch diameter heads.

Annealed and Aged, 0.065 Inch Head Stock

Previous test results had indicated the necessity of aging in the range of from 900°F to 1000°F for three hours to produce the required design yield strength of 280,000 to 290,000 psi. Therefore, a series of tensile specimens, both longitudinal and transverse, were annealed, and then aged at 50°F increments in this range. In addition, some were double aged using the temperature equal to the second aging temperature, which we expected to subsequently use for the case assembly. The exact second aging temperature was unknown at this time, but was assumed to be approximately 675°F for three hours. The precise temperature depended on the head to shell weld strength response.

The values obtained from this work are shown in Tables 10 and 11. These data are plotted in Figure 12.

It is shown from the tests of longitudinal specimens that reaging at 675°F for three hours improved the yield strength by about 5,000 to 6,000 psi over a single age at a higher temperature. The material for case manufacture would receive the double aging treatment. Based on these results, the initial aging temperature of 1025°F was selected for the production aging cycle.

Later experience showed that this temperature was too high for commercial practice. A resume' of these conditions

TENSILE PROPERTIES OF 20% NICKEL STEEL
Longitudinal Direction

Annealed at 1500°F
Cooled at -100°F, and Aged at Temperature Shown for Three Hours

Heat No. 24022
0.065 Inch Gage Strip

Spec. No.	Aging Temp. Degrees Fahrenheit	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elong. in 2 Inches
AAL-1	None	131	179	8
AAL-2	"	132	180	7
AAL-3	900	316	322	4
AAL-4	"	318	326	3
AAL-5	950	307	313	4
AAL-6	"	307	313	3.5
AAL-7	1000	290	298	3.5
AAL-8	"	290	299	3.5
AAL-9	950 + 675 *	311	317	3
AAL-10	" " "	314	319	3
AAL-11	" " "	313	319	3

TABLE 10

The Budd Co.
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TENSILE PROPERTIES OF 20% NICKEL STEEL
Transverse Direction

Annealed at 1500°F
Cooled at -100°F, and Aged at Temperature Shown for Three Hours

Heat No. 24022
0.065 Inch Gage Strip

Spec. No.	Aging Temp. Degrees Fahrenheit	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elong. in 2 Inches
AAT-1	None	136	180	6.5
AAT-2	"	134	179	6
AAT-3	900	313	322	3
AAT-4	"	315	324	3
AAT-5	950	313	320	3
AAT-6	"	312	318	3.5
AAT-7	1000	290	298	3.5
AAT-8	"	289	297	3.5

TABLE 11

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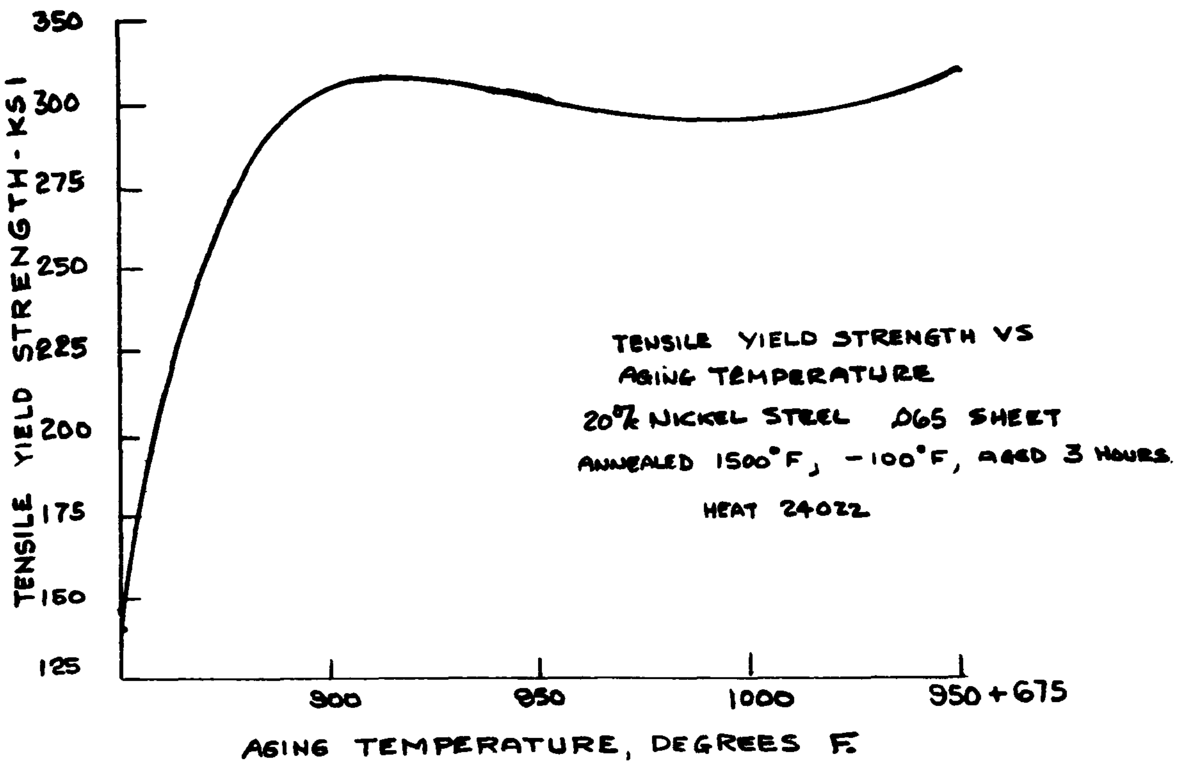

Figure 12

THE BUDD CO
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are discussed below in the section on heat treating control specimen evaluation.

Cold Rolled and Aged, 0.040 Inch Case Stock

Considerable data from the testing of cold rolled and aged 20% nickel steel sheet were published in Reports Nos. 18 and 21. Upon receipt of the 12 inch wide coil of 60% cold reduced material, for the test case fabrication, a limited number of tensile tests were made to verify the properties. These results are shown in Table 12. The aging treatments used were preceded by a sub-zero cooled at -100°F for 16 hours. The single age at 700°F and the double age at 700°F and 650°F developed equal properties. The ductility values were erratic, but all of the tensile specimens failed outside of the gage lengths.

The 12 inch wide coil of 0.040 inch thick material was approximately 175 feet long. To measure property variation, if any, from end to end of the coil, and to establish aging temperature combinations, a series of longitudinal tensile tests were made. The specimens were taken from both ends and the center section of the coil. Actually, the center section specimens were removed from 1¼ inch wide edge trim, which had been slit from the coil. The specimens from the end section were taken at random across the coil width.

Specimens were tested in the "cold rolled only" condition, and after single aging at 700°F, 725°F and 750°F.

TENSILE PROPERTIES OF 20% NICKEL STEEL
Base Metal Specimens

0.040 Inch Gage Strip
Cold Rolled 60%

Heat No. 24022
Longitudinal Specimens

Spec. No.	Mar-aging * Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elong. in 2 Inches
HNAL-1	None	202	206	3.5
-2	"	201	207	4.5
-3	"	186	191	4.0
HNRL-4	700°F, 3 hrs.	285	286	2.0 **
-5	" " "	282	282	2.0 **
-6	" " "	280	283	0.5 **
HNRL-7	700°F, 3 hrs. + 650°F, 3 hrs.	285	285	0.5 **
-8	" " " " " " "	288	290	0.5 **
-9	" " " " " " "	-	282	1.5 **

* Each aging treatment preceded by cooling at -100°F, 16 hrs.

** Specimen fractured outside of gage marks.

TABLE 12

The Budd Co.
7-62

After a review of the tensile properties, a second group were aged at the optimum initial aging temperature and re-aged at 625°F, 650°F and 675°. All aging was done for a period of three hours at temperature. Specimens were placed in a hot furnace and removed for air cooling at the end of the three hour period. Tables 13 and 14 show the data for single aged specimens. The aging at 725°F developed the 300,000 psi to 310,000 psi yield strength required by the rocket motor case design.

Re-aging at slightly lower temperatures for an additional three hours did not noticeably affect the tensile properties obtained from the single 725°F age. These data are shown in Table 15. It is well to note that in the results of the testing of specimens, single aged at 725°F or double aged at 725°F and 675°F, the spread in the ultimate tensile strength was no greater than 2½% above and below the average value of 302,500 psi. This is especially noteworthy because of the selection of specimens from widely separated areas of the coil.

Fracture energy specimens were made from material taken from both ends of the 12 inch wide coil. The specimen used was the standard 2 inch X 8½ inch center notched type, discussed and illustrated in previous reports. These test pieces were given the full double cool and age treatment. The aging temperatures were 725°F and 675°F, each for three hours. The fracture energy data are to be

TENSILE PROPERTIES OF 20% NICKEL STEEL
Longitudinal Direction
Base Metal

Cold Rolled 60%
Single Aged at Temperature Shown for Three Hours

Heat No. 24022
0.040 Inch Gage Strip

Spec. No.	Aging Temp. ** Degrees Fahrenheit	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elong. in 2 Inches
AA-8 *	None	198	206	4
-14	"	200	207	4
-19	"	197	204	4.5
BA-14 *	None	204	210	3
-19	"	200	207	3.5
CA-8 *	None	198	206	4
-14	"	198	208	4.5
-19	"	198	209	4
AA-1 *	700	-	288	1.5
-10	"	-	288	0.5
-15	"	286	286	1.0
BA-15 *	700	288	288	1.0
CA-1 *	700	288	288	-
-10	"	278	278	1.5
-15	"	282	282	1.5

* First letter in identification (A, B or C) indicates specimens taken from one end, middle, or other end of 12 inch wide coil.

** Aging preceded by -100°F, 16 hours.

TABLE 13

The Budd Co.
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TENSILE PROPERTIES OF 20% NICKEL STEEL
Longitudinal Direction
Base Metal

Cold Rolled 60% | Heat No. 24022
Single Aged at Temperature Shown for Three Hours | 0.040 Inch Gage Strip

Spec No.	Aging Temp. ** Degrees Fahrenheit	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elong. *** in 2 Inches
AA-5 *	725	305	305	1.5
-9	"	306	306	1.0
-16	"	306	306	1.0
BA-9 *	725	306	306	1.5
-16	"	308	308	1.0
CA-5 *	725	295	295	2.0
-9	"	306	306	1.5
-16	"	305	305	-
AA-4 *	750	323	323	1.5
-13	"	319	319	1.5
-17	"	318	318	1.5
BA-17 *	750	326	326	1.5
-				
CA-4 *	750	309	309	1.0
-13	"	316	317	1.5
-17	"	321	322	0.5

* First letter in identification (A, B or C) indicates specimens taken from one end, middle or other end of 12 inch wide coil.

** Aging preceded by -100°F, 10 hours.

*** All specimens broke across gage marks.

TABLE 14

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TENSILE PROPERTIES OF 20% NICKEL STEEL
Longitudinal Direction

Cold Rolled 60%
Initial Age at 725°F, plus Second Age at Temperature Shown **

Heat No. 24022
0.040 Inch Gage Strip

Spec. No.	Second Aging Degrees Fahrenheit	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elong. in 2 Inches
AA-2 *	625	-	308	1.5
-11	"	306	306	1.5
-18	"	304	304	1.5
BA-18 *	625	305	305	1.5
CA-2 *	625	300	300	1.5
-11	"	298	298	1.5
-18	"	306	306	1.5
AA-3 *	650	-	305	1.5
-7	"	309	310	1.5
-20	"	-	296	1.0
BA-20 *	650	-	302	1.5
CA-3 *	650	-	301	1.5
-7	"	-	297	1.5
-20	"	-	304	1.5
AA-6 *	675	-	305	1.5
-12	"	-	304	1.5
-21	"	306	306	1.0
BA-21 *	675	305	305	1.5
CA-6 *	675	298	298	1.5
-12	"	305	305	1.5

* First letter in identification (A, B or C) indicates specimens taken from one end, middle or other end of 12 inch wide coil.

** Second aging preceded by -100°F, 16 hours.

TABLE 15

The Budd Co.
7-62

found in Table 16. The K_{c1} values are converted to G_c for the readers' convenience. The conversion is based on a probable modulus of elasticity of 26 X 10^6 psi. Previous tests had indicated slightly lower fracture toughness at the same strength level.

From this study the 725°F initial base metal aging temperature was selected to develop adequate base metal properties. The second aging temperature, expected to be in the range of 625°F to 675°F would be established based on the required weld strengths, which will be discussed in the next section.

Welding of 20% Nickel Mar-aging Steel (Heat No. 24022)

T.I.G. Welding of Cold Rolled Material

The results of an exploratory examination of the welding of 20% nickel steel were discussed in quarterly Report No. 21. At that time we had made our investigation using both annealed and cold rolled and aged material. The filler wire was of a matching analysis and, like the base contained high titanium (1.68%), high aluminum (0.42%), and high columbium (0.47%).

The results obtained, as shown by the tensile test data, were very satisfactory. The strengths were greater than expected and the ductility across the welded joint was ample. However, in anticipation of the production lot of

FRACTURE ENERGY PROPERTIES OF 20% NICKEL STEEL

Cold Rolled 60%
Initially Aged 725°F, 3 hrs. *
Second Age 675°F, 3 hrs. *

Longitudinal Direction
Heat No. 24022
0.040 Inch Gage Strip

Spec. No.	Yield Strength KSI σ Y.S.	K_{c1} PSI $\sqrt{\text{Inch}}$	G_c Pound/Inch
AB-1	305	2	-
AB-2	"	104,200	450
AB-3	"	2	-
CB-1	305	110,000	475
CB-2	"	108,000	460
CB-3	"	100,000	370

* Each aging treatment preceded by cooling at -100°F for 16 hours.

NOTE: First letter indicates specimens taken from one end (A) or other (C) from 12 inch wide coil.

TABLE 16

The Budd Co.
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material to be used for actual case construction, we consulted with International Nickel Company metallurgists to establish a new welding wire analysis. The aim was to gain maximum ductility and sacrifice some strength, if necessary.

At this phase of the overall program, it had been tentatively established that the welded cylindrical case would require an initial aging temperature of 725°F. The design required a weld joint yield strength normal to the weld of 190,000 psi to 210,000 psi. Aging at 725°F had developed weld strengths in excess of this range. Therefore, it was considered advisable to reduce the hardener element content of the weld wire. The titanium was reduced from a nominal 1.80% to 1.60%. The aluminum content was lowered from 0.50% to 0.25%. In one heat of the steel a molybdenum content of 1.50% was added. We were informed that previous work by INCO, with filler wire containing molybdenum in this percentage, had shown improved results in respect to ease of welding and subsequent mechanical properties.

The product of two 50 pound ingots, one with molybdenum and one without, were made and drawn into 0.032 inch diameter wire by Allegheny-Ludlum. The analyses of these heats are shown in Table 17.

The techniques of welding the 20% nickel alloy had been established in previous work. The present aim was to verify the welding procedure using the 0.040 inch cold rolled

WELDING WIRE ANALYSES
20% Nickel Steel

Source: Allegheny Ludlum Steel Corporation

Diameter: 0.032 inch.

	Heat No. 7C088	Heat No. 7C089
Carbon	.029	.030
Manganese	.003	.003
Phosphorus	.008	.008
Sulphur	.007	.006
Silicon	.005	.050
Chromium	.006	.007
Nickel	19.72	19.72
Molybdenum	--	1.50
Titanium	1.62	1.62
Columbium	.43	.46
Aluminum	.26	.26
Iron	Bal.	Bal.

TABLE 17

The Budd Co.
7-62

material procured for the test cases, using the two filler wires.

Test panels were made according to the welding schedule shown in Figure 13. Tensile specimens were tested "as welded", after single aging at 700°F for three hours, and after double aging at 700°F and 650°F each for three hours. The test results are shown in Tables 18 and 19. Filler wire heat No. 7C088 is of the straight, lower hardener analysis. Heat No. 7C089 contains 1.5 Mo.

The tensile properties are in the range expected and the ductility is adequate. The strengths obtained with both filler wires, using a 700°F aging temperature, were lower than had been realized previously using matching analysis wire. Not enough specimens were tested to indicate any significant improvement of ductility. All fractures occurred in the heat affected zone at the base metal to weld deposit interface area. The molybdenum bearing wire produced tensile properties higher than the straight analysis filler. No difference in weldability could be detected in the use of the two wires.

These tests verified the acceptability of the welding procedure. The decision was made to use the straight analysis wire, heat No. 7C088.

In the T.I.G. arc welding evaluation of the 20% nickel alloy, we have to date worked with two heats of base metal

TIG WELDING SCHEDULE

Material: 20% Nickel Steel, Heat No. 24022, 0.040 Inch.

Filler Wire A *: Matching Analysis With Lower Ti and Al.

Filler Wire B *: Matching Analysis With Lower Ti and Al, plus 1.5% Mo.

Gage Inches	Material Condition	Wire Type	Weld Current Amperes	Arc Voltage Volts	Travel Speed In./Min.	Wire Diameter Inches	Wire Feed In./Min.	Electrode Diameter Inches
0.040	Cold Reduced 60%	A	70	9	7	.032	22	1/16
0.040	Same	B	62	9	5	.032	20	1/16

Welding conditions common with the use of both welding wires.

1. Weld current is direct current, straight polarity (DCSP).
2. Backup plate, copper, (Drawing No. 2434-0103), groove 0.050" X 0.250", with gas ports.
3. Stainless steel chill bars at 3/4" spacing, 45° bevel, 5/16" land.
4. Run-off tabs used on all panels.
5. Wire mechanically cleaned and degreased prior to welding.
6. Torch gas - argon at 30 CFH; trail gas - argon at 15 to 20 CFH; backup gas - helium at 6 to 12 CFH.

* See Table 17 for suppliers analyses of welding wire.

FIGURE 13

The Budd Co.
7-62

TENSILE PROPERTIES OF 20% NICKEL STEEL
TIG Welded Specimens

Base Metal, 0.040 Inch Gage Strip
Heat No. 24022; Cold Rolled 60%

Filler Wire, 0.032 Inch Diameter
Modified Analysis, Heat No. 7C088

Spec. No.	Mar-Aging Treatment *	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation 1/2"	1"	2"	Location of Fracture
HNCT-2	None	175	177	11	6	2	HAZ **
-3	None	161	168	12	5	2	"
HNCT-4	700°F, 3 hrs.	200	202	5	2	1.5	HAZ **
-5	700°F, 3 hrs.	195	199	6	3	2.0	"
-6	700°F, 3 hrs.	199	201	7	3.5	2.0	"
HNCT-7	700°F, 3 hrs. + 650°F, 3 hrs.	202	204	7	3.5	2	HAZ **
-8	700°F, 3 hrs. + 650°F, 3 hrs.	204	204	2	1	1	"
-9	700°F, 3 hrs. + 650°F, 3 hrs.	192	192	2	1	1	"

* Each aging treatment preceded by cooling at -100°F, 16 hours.

** HAZ - Heat affected zone.

TABLE 18

The Budd Co.
7-19-62

TENSILE PROPERTIES OF 20% NICKEL STEEL
TIG Welded Specimens

Base Metal, 0.040 Inch Gage Strip
Heat No. 24022; Cold Rolled 60%

Filler Wire, 0.032 Inch Diameter
Modified Analysis with 1.5 Mo, Heat No. 7C089

Spec. No.	Mar-aging Treatment *	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation 1/2"	1"	2"	Location of Fracture
HNCT-10	None	170	172	8	4	2	HAZ **
-11	None	173	174	4	2	1	"
HNCT-12	700°F, 3 hrs.	-	188	3	1.5	1	HAZ **
-13	700°F, 3 hrs.	-	209	5	2.0	1.5	"
-14	700°F, 3 hrs.	209	209	3	1.5	1.0	"
-15	700°F, 3 hrs. + 650°F, 3 hrs.	208	209	4	1.5	1.0	HAZ **
-16	700°F, 3 hrs. + 650°F, 3 hrs.	208	208	4	2.0	1.5	"
-17	700°F, 3 hrs. + 650°F, 3 hrs.	216	216	4	2.0	1.0	"

* Each aging treatment preceeded by cooling at -100°F, 16 hours.

** HAZ - Heat affected Zone.

TABLE 19

The Budd Co.
7-62

and three heats of filler wire. Welding was accomplished with equal ease with all combinations of base metal and filler wire. The tensile properties were very satisfactory, being predictable and reproducible. Weld quality, as measured by X-Ray and penetrant inspection methods, was uniformly excellent.

AM-359 Stainless Steel (Ref. Report Nos. 4 and 12)

The AM-359 alloy is a precipitation hardening stainless steel developed by the Allegheny-Ludlum Steel Corporation. It differs from the AM-350 or AM-355 grades in that it contains a sufficient amount of aluminum to develop the true precipitation hardening effect. The delta ferrite content in the alloy is very low, compared to other stainless steels of a similar type.

The chemical composition of the alloy is shown in Table 5. The density is approximately 0.282 pounds per cubic inch in the heat treated condition and 0.286 in annealed condition.

The heat treatments used for AM-359 are similar to those employed for the AM-350 and AM-355 alloys. The two main heat treating processes are designated "SCT" (subzero cooled and tempered) and "DA" (double aging). In the SCT treatment, sheet material annealed at 1875°F to 1900°F, as supplied by the mill, is used. A "trigger" anneal of 1750°F, followed by air cool, causes sufficient carbide

precipitation to take place to unbalance the chemistry and create a condition of phase instability. Transformation takes place from the M.S. temperature down to room temperature and beyond. Cooling to -100°F for six hours guarantees the complete transformation. A tempering treatment at a temperature range from 800°F to 1000°F for one to one and a half hours increases hardness and tensile strength.

The DA (double aging) treatment is not generally recommended by the producer for this grade of steel, because properties are lower than SCT treatment and corrosion resistance is reduced. Aging of fully annealed material is accomplished at about 1400°F; this is followed by a second aging at 900°F to 1000°F, where a precipitation of compounds occurs which increases hardness and strength.

A summary of typical data obtained from Allegheny-Ludlum and from The Budd Company evaluation is shown in Table 20.

With the development of a suitable heat treat sequence, a possible tensile strength of 280,000 psi seems possible. Its high elongation indicates suitability for room temperature forming of rocket motor heads and closures where a strength density ratio of 0.98×10^6 could be achieved after heat treatment.

MECHANICAL PROPERTIES OF AM-359

Material	Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % in 2"	Reduction Area	Hardness R_c	Remarks
1" Dia. Bar *	Room Temperature	235	253	8	26	51	
Allegheny-Ludlum	600°F	189	216	8½	29	-	
Heat 23009	800°F	164	197	11	39	-	
S.C.T. Treatment	1000°F	112	136	18	55	-	
	1100°F	62	85	40	75	-	
Strip *	Cold Reduced 40%	276	285	2	-	54	
Various Gauges	Cold Reduced 50%	295	306	1½	-	58	
Heat 23009	Cold Reduced 60%	305	314	Nil	-	57	
.060 Strip **	Annealed 1860°F	L-45	132	55	-	-	Av. 4 Specs.
	Air Cooled	T-49	142	38	-	-	Av. 4 Specs.
	Anneal 1860°; Air Cooled; 1750°F, 10 Min.; Air Cool; -100°F, 6 hrs.; Air Warm; 935°F, 1½ hrs.; Air Cool	L-197	226	8	-	-	Av. 4 Specs.
		T-200	230	6	-	-	Av. 4 Specs.

* Allegheny-Ludlum data
** Budd Company data

L = Longitudinal Tensile
T = Transverse Tensile

TABLE 20

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AM-357 Stainless Steel (Ref. Report No. 3)

This alloy developed, by Allegheny-Ludlum Steel Corporation, is a modification of their original AM-350 and AM-355 grades. High strength is obtained in this alloy through strain hardening and/or heat treatment. After strain hardening and heat treatment the material is martensitic.

The chemical analysis of the alloy is shown in Table 5.

The heat treatment used for the AM-357 alloy is designated SCT (sub-zero cool and temper). Material is initially solution annealed at a temperature range of 1875°F to 2000°F. This is followed by a second high temperature "trigger" anneal at approximately 1710°F. Time at temperature is short but sufficient to allow precipitation of the chromium carbides. Cooling at -100°F causes the transformation of the unstable austenite to a strong martensitic structure. After sub-zero cooling, the alloy is given a tempering treatment at temperatures of 850°F to 1000°F for three hours to further improve the strength.

Cold reduction promotes the transformation of austenite to martensite. The amount of transformation is a function of the degree of deformation. Reductions in sheet product of 55% to 65% results in very little retained austenite.

CRT is the designation used for the cold rolled and tempered condition. The tempering temperature of 750°F to 900°F is used to further improve the properties after rolling.

Another condition possible with this alloy is XH (extra hard). It is achieved by extensive cold reduction, beyond that usually employed for the CRT condition. It is presently used only for very light gage coil stock.

Still another condition is SCCRT, which is achieved by heat treatment (SC), cold rolling (CR), and tempering (T). The sub-zero cooling encourages the transformation of austenite to martensite. The cold rolling insures complete transformation as well as inducing strain hardening. The subsequent aging of the strain hardened martensite increases the strength to the maximum value.

Table 21 is a summary of the mechanical properties of the AM-357 alloy in various conditions. These data were furnished by Allegheny-Ludlum Steel Corporation.

The cold reduced strip material, ordered for evaluation, was delayed in delivery due to processing difficulties at the mill. For this reason, and because of the availability of other alloys having more attractive properties, particularly in weld strengths, a decision was made to not continue testing of this alloy.

PH 12-8-6 Stainless Steel (Ref. Report No. 15)

The Armco Steel Corporation developed a precipitation hardening stainless steel designated PH 12-8-6. This alloy is similar to their PH 17-7 and PH 15-7 Mo grades and uti-

MECHANICAL PROPERTIES OF
AM-357 STAINLESS STEEL

Material	Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % in 2"
.060 Sheet Cold Rolled	Solution Annealed 1710°F; Water Quench -100°F, 3 hrs.; Age 850°F, 3 hrs.	193	235	15
0.019 Sheet	CRT	303	310	15
0.030 Sheet	SCCRT	322	331	3.5
0.015 Sheet	XH	356	361	2.0
.260 Plate *	Annealed	L 74	120	8
	As Received	T 70	130	12

* Budd Co. Data

TABLE 21

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lizes like heat treating and processing techniques. The composition of this alloy is shown in Table 5. The analysis was designed to give the alloy higher strengths at room temperature and at elevated temperatures. Aluminum has been added as the PH hardening agent.

The density of the alloy varies with the metallographic structure. Values for annealed and two heat treated conditions are listed below:

Condition	Density, lb./in.^{3}
A (Annealed)	0.286
T 25 MH	0.282
T 25 H1000	0.281

The material received from Armco was primary vacuum melted and vacuum consumable electrode remelted.

Annealing (Condition A) the alloy is done by heating to 2000°F, followed by air cooling. In this condition the material is austenitic and possesses good ductility.

In the T 25 H1000 condition, annealed material is heated to 1400°F for two hours and cooled in air. This is followed by refrigeration at -25°F for two hours minimum and then hardening at 1000°F for two hours and air cooled. The 1400°F treatment allows carbide precipitation to occur which unstabilizes the austenitic structure and allows the transfer to martensite when cooled to -25°F. Associated with the trans-

formation is a dimensional growth, which reduces the density. The final precipitation hardening is done by aging at 1000°F.

The condition T 28 MH heat treat cycle begins with the material in annealed condition. It is then heated to 1400°F for two hours, followed by air cooling. This is followed by refrigeration at -25°F for two hours. Hardening is accomplished by heating at 1000°F for two hours, furnace cool to 950°F, hold for three hours, furnace cool to 900°F for three hours, followed by air cool to room temperature. The aging at three different temperatures is done to gain maximum strength improvement from the precipitation hardening effect.

A summary of tensile properties determined from material in the annealed and T 25 MH conditions is shown in Table 22. The yield strengths are low in the annealed condition with a yield strength to tensile strength ratio of approximately 0.33. High elongation increases the formability. The strength is considerably increased as a result of the T 25 MH treatment. The ductility is reduced and the yield strength to density ratio is slightly less than 1 X 10^6 inch.

No fracture energy testing was done with this alloy, although an indication of low toughness at high strength levels was apparent from the nature of the fractures on tensile specimens.

No additional evaluation was done on this alloy since it became evident that a considerable sacrifice in strength

MECHANICAL PROPERTIES OF
ARMCO PH 12-8-6 ALLOY

Material	Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % in 2"	Hardness	Remarks
.062 ARMCO Heat VO 31042	Solution Annealed	L 52	154	30	88 R_b	Av. of 4 Specimens
		T 50	152	30	87 R_b	Av. of 4 Specimens
.062 ARMCO Heat VO31042	T-25 M.H. 1400°F, 2 hrs. -25°F, 2 hrs. 1000°F, 2 hrs. 950°F, 3 hrs. 900°F, 3 hrs.	L 277	300	1.5	56 R_c	Av. of 4 Specimens
		T 276	300	2	56 R_c	Av. of 4 Specimens

TABLE 22

would be required to gain satisfactory toughness for rocket case application.

The PH 12-8-6 alloy would be more applicable in the yield strength ranges of 250,000 psi to 270,000 psi where ductility and fracture toughness would probably improve.

JLS-300 Stainless Steel (Reports 9, 10, 11, 12, 18)

The JLS-300 alloy is an austenitic stainless steel similar to AISI Type 301 and is produced by Jones and Laughlin Steel Corporation. It responds readily to strain hardening and strain induced martensitic transformation to produce yield and ultimate strengths in excess of 300,000 psi. A slightly higher carbon and nitrogen content contributes to the higher strength of the alloy.

The chemical composition is shown in Table 5.

Some physical properties of the alloy are:

Density	- 0.285 lb./cu.in.
Modulus of Elasticity	- 27.3×10^6 psi

Material for evaluation was received in 0.040 inch thickness and in two widths, $6\frac{1}{2}$ inch and 10 inch cold rolled strip. Tensile properties of the material are summarized in Table 23. Ultimate tensile strengths as high as 350,000 psi were recorded with elongation of 1.0%. The values compare with data obtained by Jones and Laughlin.

MECHANICAL PROPERTIES OF * JLS-300 STAINLESS STEEL

Material	Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % in 2"	Hardness	K_{cl} PSI Inch	$\frac{Y.S.}{d \times 10^6}$	Remarks
.040 X 6½" Strip J & L Heat 61616	Cold Rolled Aged	L 341	345	1.5	R_c57	-	-	Average of 4 Specs.
.040 X 10" Strip J & L Heat 61616	Cold Rolled Aged	L 344	346	1.5	R_c57	-	-	Average of 2 Specs.
		T 330	351	2.0	R_c57	-	-	
.040 X 10" Strip J & L Heat 61616	Cold Rolled Aged	L 344	346	2.0	-	124,000	1.21	Average of 4 Specs.
		T 330	341	2.5	-	55,000	1.16	Average of 4 Specs.
.040 X 6" Strip J & L Heat 61616	Cold Rolled Aged	L 344	345	2	-	109,000	1.21	Average of 2 Specs.

* Jones and Laughlin Steel Corporation

TABLE 23

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Tungsten inert gas welding characteristics of JLS-300 alloy were evaluated. Twelve inch weldments were made using .040 inch thick material, which was cold rolled and tempered (CRT) to a yield strength of approximately 340,000 psi. The weld schedule is shown in Table 24.

The weldability of JLS-300 is good, being quite similar to AISI 301 stainless steel. The ratio of the yield strength of the weldment to yield strength of the base metal (CRT condition) is low, approximately 27%. Similarly the ratio of the tensile strength of the weldment to the base metal tensile strength is about 60%.

Electron beam weldments were made using JLS-300 alloy. This was a single pass weld and a specimen taken from the weldment 90° to the weld line. Excessive porosity and microcracks were evident in single pass weld, but condition was eliminated on multiple pass (3) welds. Data from this series of specimens are summarized in Table 25. It should be noted that increases of 30% to 35% were realized in yield strength of the welds made by electron beam process. No difference was noted in ultimate tensile strength.

The low weld yield strength to base metal yield strength ratio and the lack of a practical method of uniformly strain hardening the weld area was a major reason for not using this alloy in the rocket case design.

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T.I.G. FUSION WELDING SCHEDULE FOR JLS-300 MATERIAL
AND AM-355 FILLER METAL

ITEM	DISCRIPTION OF ITEM
Electrode	
Type	2% thoriated tungsten
Size	1/16" diameter pointed
Stickout	9/32"
Torch	
Type	AIRCO Model "C"
Attack Angle	90°
Lead Angle	Zero
Nozzle	Ceramic No. 4, 5/8" diameter
Root Shield	
Type	Copper - Budd Company Drawing E2434-0121 (Figure 4)
Groove Size	0.015" deep X 0.125" wide
Gas Ports	1/16 diameter, spaced 3/4" apart
Chill Bars	Copper, 3/4" X 3-1/4", with 45° bevel along length
Arc Voltage	10 volts at electrode tip
DSCP Amperage	95/100 amperes
Shielding Gas	
Nozzle	Argon 30 cubic feet per hour
Root	Argon 6 cubic feet per hour
Filler Wire	
Type	AM-355, annealed
Size	1/16" diameter
Feed	20 inches per minute
Welding Speed	18 inches per minute
Preheat	None
Postheat	None
Power Source	Vicker's 300 amperes rectified

TABLE 24

MECHANICAL PROPERTIES OF

T.I.G. AND ELECTRON BEAM WELDMENTS - * JLS-300 ALLOY, AM-355 FILLER WIRE

Material	Condition	0.2% Yield Strength KSI	Tensile Strength KSI	Elongation % $\frac{1}{2}$"	Elongation % 2"	Location of Fracture	Remarks
.040 X $6\frac{1}{2}$" CRT Strip	T.I.G. Welded, AM-355 Filler Wire As Welded	92	208	12	3	HAZ	Average of 4 Specimens
.040 X $6\frac{1}{2}$" CRT Strip	T.I.G. Welded, AM-355 Filler Wire Weld Reinf. Removed	87	200	12	3	HAZ	Average of 4 Specimens
.040 X $6\frac{1}{2}$" CRT Strip	Electron Beam Welded As Welded	120	200	12	2	HAZ	Average of 3 Specimens

* Jones and Laughlin Steel Corporation

TABLE 25

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A basic resistance welding study was made on JLS-300 steel. The alloy responds to resistance welding in a manner similar to AISI Type 301 stainless steel. In the cold rolled and aged condition the structure is tempered martensite with some retained austenite. The weld nugget is a cast structure which is surrounded by material in the annealed austenitic condition as a result of the heat of welding.

Table 26 tabulates the results of the mechanical tests on tensile shears and tension specimens. The ratio of tensile to tensile-shear (68.4%) indicates good ductility and weld toughness of resistance welded JLS-300. The welding schedule is shown in Figure 14.

A limited corrosion study was made on JLS-300 stainless steel in the cold rolled and aged condition at 345,000 psi tensile strength. Spot welded specimens were exposed to both a 5% and 20% boiling M_gCl_2 solution. Specimens were examined by microscope after one-half hour, one hour, two hours, eight hours, 14 hours and each 24 hour period up to five days. The results of these tests are summarized in Table 27.

The fracture toughness of JLS-300 alloy as indicated by K_{cl} values was determined for strip material at a yield strength level of 344,000 psi. Data is shown in Table 23. The K_{cl} values in the longitudinal direction are very good for material at the high strength level. Toughness in the transverse direction is less. Compared to other alloys at

MECHANICAL PROPERTIES
RESISTANCE SPOT WELDED SPECIMENS
JLS-300 MATERIAL

Material	Condition	Tensile Load Lbs.	Tensile Type Failure	Tensile-Shear Load Lbs.	Tensile-Shear Type Failure	Tensile / Tensile-Shear Ratio
.040 X 10" Strip J & L Heat 61616	Cold Rolled and Aged	1774	Plug	2593	Shear	68.4%

TABLE 26

The Budd Co.
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MATERIALS RESEARCH LABORATORY

Resistance Welding Data Sheet

Date: 4-24-61

Project: 2434

Welding Machine	Material and Gage
Sciaky 150KVA, Single Phase	0.040" JLS-300 (FN)

Electrodes	Material Condition
5/8" diameter RWMA Grade A, Class 3,	Cold Rolled and Aged
2-1/2" Radius	

Welding Schedule

Electrode Force, lbs.		Phase Shift, %	35
Net	1100		
Forge	-		
Weld Cycles	7	Weld Diameter, inches	0.183
Impulses	1	HAZ Diameter, inches	0.220
Cooling Cycles	-	Penetration, %	71
Transformer Setting	2 series top 2 *	Electrode Indentation, %	7.5

* Approximately 7000 amperes, Duffer Meter Reading

Remarks and Special Functions

Squeeze 50 Cycles, hold 50 Cycles

Figure 14

STRESS - CORROSION TESTS ON JLS-300 STAINLESS STEEL

RESISTANCE SPOT WELDED SPECIMENS

Condition	Type of Solution	Specific Gravity Start	Specific Gravity Finish	Total Hours	Remarks
Cold Rolled and Aged	5% M_gCl_2 *	1.020 at 83°F	1.023 at 73°F	116	3 Specimens OK 1 Specimen cracked after 16 hours.
Cold Rolled and Aged	20% M_gCl_2 *	1.075 at 89°F	1.073 at 90°F	126	All 4 Specimens OK after 126 hours. Some pitting in area of weld electrode.

* Boiling acqueous solution

TABLE 27

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the same yield strength level, the values appear to be reasonably high.

In summary, the JLS-300 alloy would be highly desirable in rocket case designs where low annealed weld strength could be tolerated. In the design of helically welded case, a weld strength of 60% to 75% of the base metal yield strength is required. It is not presently practical to attain this in the JLS-300 alloy. For this reason, no additional work was done on the material.

Titanium 6Al-6V-2Sn Alloy (Ref. Reports 7 and 15)

This titanium alloy is an alpha-beta alloy which is produced principally in the form of rods, billets and bars. It has recently been processed into sheet form and significantly higher strength has been reported than was obtained in the heavier wrought products.

This analysis of the alloy is shown in Table 5. The density is calculated at 0.1621 lbs./in.^{3}.

Heat treatment of this alloy to obtain maximum aging response requires a quench from the solution annealing temperature of 1650°F to room temperature (70°F-80°F) in five seconds. This requires a water quench which causes distortion in sheet or strip product. This process could be a major problem in the production of strip material. The material, as received for evaluation, had been vacuum

annealed at 1300°F, and air annealed at 1525°F. The surface was grit blasted, pickled and surface ground to remove scale. The material was solution annealed at 1650°F, then aged at 1050°F by The Budd Company. This treatment was selected to attain maximum tensile properties. Ductility at this strength level was low, however, the strength to density ratio was 1.34 X 10^6 inch. Fracture toughness as measured using the center notch specimen showed very low values at the high strength. This possibly could be improved at lower levels, however, it is questionable whether sufficient toughness could be attained to make the alloy competitive with other alloys. Data are summarized in Table 28.

Preliminary investigation into the fusion weldability of titanium 6Al-6V-2Sn alloy was made using the T.I.G. bead on plate technique. Filler wire was not available, and attempts by wire vendors to make a suitable wire were unsuccessful.

Transverse tensile weld specimens were made from the bead on plate weldments. Specimens were heat treated at 1625°F, water quenched, then aged at 950°F for one hour. It was determined that during the manufacture of the tensile specimens that welds were crack sensitive and extremely brittle. No tensile data were obtained on fusion welded specimens.

No difficulty was encountered in developing a schedule

MECHANICAL PROPERTIES OF
Ti 6Al-6V-$2S_n$ ALLOY (HEAT 29536)

Mat'l.	Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % in 2"	Hardness R_c	$\frac{K_{c_1}}{PSI\sqrt{Inch}}$	$\frac{Y.S.}{Density} \times 10^6$	$\frac{K_{c_1}^2}{\mathcal{C}^2\, Y.S.}$	
.097 Sheet	Annealed 1525°F. 3/4 hr.; Furnace Cool to 1100°F.; Air Cool	L 143	152	13	35	-	-	-	*
		T 150	157	11.5	-	-	-	-	*
.088 Sheet	Age 1050°F, 1 hr.; Air Cool	L 212	218	2.0	47	-	-	-	*
		T 212	218	1.0	47	-	-	-	*
.085 Sheet	Anneal 165°F.; Water Quench; Age 1050°F., 1 hr.; Air Cool	L 211	219	-	-	28	1.30	.005	*
		T 212	218	-	-	27	1.31	.005	*

* Average of 4 Specimens Each.

MECHANICAL PROPERTIES
RESISTANCE SPOT WELDED SPECIMENS
Ti 6Al-6V-$2S_n$ ALLOY (HEAT 29536)

Condition	Tensile Specimen Load Lbs.	Tensile Specimen Type Failure	Tensile Shear Specimen Load Lbs.	Tensile Shear Specimen Type Failure	Tensile/Tensile Shear Ratio
Solution Annealed and Aged at 1050°F., 1 hour.	700	*	3271	*	0.21

* Material fractured in base metal due to bending stresses. Brake originated in weld heat affected zone.
Average of 4 Specimens.

TABLE 28

The Budd Co.
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to resistance spot weld 0.088 inch thick test material. A good quality porosity free nugget was produced. Nugget hardness was slightly less than R_c35. Table 28 shows the direct tensile and tensile-shear strength values of spot welds. There was evidence that failure was initiated in the heat affected zone. With lower strength base metal having greater ductility, the weld nugget would probably fail either by shear or by pulling the nugget out of the sheet.

This alloy was evaluated at only one strength level and exhibited low ductility and fracture toughness. Weldability appeared to be good, although tensile data was not obtained. Sound spot welds were made. The requirement for water quenching this alloy after solution treatment is a disadvantage in the production of strip product.

Titanium 8Al-10V Alloy (Report No. 15)

The alpha-beta titanium alloy Ti 8Al-10V was evaluated. This material, produced by Republic Steel Corporation, was developed as a forging alloy, however, sheet material has been produced recently. Sheet material from two heats, .060 inch thick, was made on an experimental basis. The sheet stock used in this evaluation was obtained in the solution annealed condition.

The composition of the alloy is shown in Table 5.

The density is reported as 0.162 $lbs./in.^3$.

The hardening process for the Ti 8Al-10V alloy consists of solution annealing at 1500°F, air cooling at room temperature. This was followed by aging at 1050°F for 1½ hours. Other solution and aging treatments could be used, depending on the properties required. All test specimens were aged in air, prior to final machining, then pickled to remove the light oxide coating, plus .001 inch material removed from all surfaces. This was done to prevent any contamination from affecting the mechanical properties. The pickling solution was

HF	-	2 to 2½%
HNO_3	-	18 to 20%
Water	-	Balance

The mechanical properties of Ti 8Al-10V alloy .060 sheet material are summarized in Table 29. The values obtained were similar to those reported by the supplier, Republic Steel Corporation. An aging temperature of 1050°F for 1½ hours was selected to obtain maximum strength values. Yield strength of 200,000 psi and ultimate strengths of 212,000 psi were attained, which is comparable to data reported at this mill.

The bend capability of the alloy at the high strength level was, as would be expected, very low. Bend specimens broke after only slight bending. The strength level appeared to be higher than practical.

MECHANICAL PROPERTIES OF TI 8AL-10V ALLOY

.060 THICK SHEET MATERIAL

Heat No.	Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	% Elong. in 2 Inches	Hardness R_c	* Fracture Toughness $K_{c1}\sqrt{\text{Inch}}$	$\frac{\text{Y.S.}}{\text{Density}} \times 10^6$	$\frac{K_{c1}^2}{\sigma \text{ Y.S.}}$	
70032 Republic Steel	Sol. Annealed	L - 64 T - 72	157 164	6.5 5.5	33 33	- -	- -	- -	Av.3 Spec. Av.4 Spec.
	Sol.Annealed Aged 1050°F, 1½ Hours	L - 208 T - 209	220 218	2.0 1.5	46 46	- -	- -	- -	Av.3 Spec. Av.3 Spec.
70033 Republic Steel	Sol.Annealed	L - 61 T - 69	146 156	4.0 5.0	31 31	- -	- -	- -	Av.3 Spec. Av.3 Spec.
	Sol.Annealed Aged 1050°F, 1½ Hours	L - 202 T - 200	212 211	3.0 3.5	47 47	- -	- -	- -	Av.3 Spec. Av.3 Spec.
70032 Republic Steel	Sol.Annealed Aged 1050°F, 1½ Hours	L - 207 T - 210	219 219	- -	- -	19,500 15,000	1.28 1.30	.003 .002	Av.2 Spec. Av.2 Spec.
70033 Republic Steel	Sol.Annealed Aged 1050°F, 1½ Hours	L - 202 T - 201	212 211	- -	- -	18,000 19,000	1.25 1.25	.003 .003	Av.3 Spec.

* Center Notch Specimen - Drawing #2434-0014

TABLE 29

The Budd Co.
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Fracture toughness of the alloy, measured by the K_{cl} value is shown in Table 29. These values are very low and indicate low fracture toughness of the alloy at the high strength, however, values were quite uniform. Yield strength to density ratio was 1.25 inches, and it is likely that at a lower yield strength, the toughness would improve. It is questionable, however, that toughness would be satisfactory for rocket case work, even at a much lower yield strength.

A T.I.G. fusion welding study was made on the Ti 8Al-10V alloy. Bead-on plate welds were used due to our inability to obtain filler wire. Welding conditions are summarized in Table 30. In this series of tests an attempt was made to find a weld-heat treatment sequence that would result in a weld of acceptable ductility and at the same time preserve the base metal strength. This work employed bend test specimens where the bend was along the longitudinal certerline of the weld. Material was welded in the solution annealed condition and in the aged conditions. Bend test data are summarized in Table 31. All welds were brittle with failures occurring in the weld deposit and none were capable of bending more than 20 degrees from the flat. The specimen did not follow a 7/8 inch radius.

Torch annealing of the weld at 1500°F, followed by aging, was tried to improve ductility and strength. This produced a tendency to harden in the solution treated base metal immediately adjacent to the weld, and the weld deposit hardness was

TUNGSTEN INERT GAS WELDING CONDITIONS

MATERIAL: Ti 8Al-10V

Material Condition	Weld Current Amps.	Arc Voltage	Torch Gas Type	Torch Gas Flow $Ft.^3/Hr.$	Backup Gas Type	Backup Gas Flow $Ft.^3/Hr.$	Weld Travel In./Min.
Solution Annealed	85-90	10	Argon	25	Argon	3	10
Solution Annealed and Aged	120	10	Argon	25	Argon	3	10

1/16 diameter, 2% Thoriated Tungsten Electrode, Conical Point Electrode

Stick-out 7/16", 5/8" diameter Metallic Nozzle.

Copper Backup Bar with 0.040" X 3/16" Relief Plus Gas Ports.

Hold-down Spacing of 1/4".

Material was cleaned with 400 Grit Silicon Carbide Paper, washed with

Acetone, and pickled in 40% Sulphuric Acid.

TABLE 30

The Budd Co.
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HEAT TREATMENT OF BEAD-ON-PLATE WELDMENTS

Ti 8Al-10V   0.060" Gage   Heat No. 70032

Specimen Number	Material Condition When Welded	Re-solution Treatment After Welding *	Aging Treatment After Welding **	Bend Radius	Base Metal RC Hardness
A-1	Solution Annealed	1575°F	1050°F	15T	48
A-2	Solution Annealed	1550°F	1050°F	15T	46
A-3	Solution Annealed	1500°F	1050°F	15T	44
A-4	Solution Annealed	1450°F	1050°F	15T	42
A-1A	Solution Annealed	1350°F	1050°F	15T	48
A-5	Solution Annealed	-	1050°F	15T	46
B-1B1	S.A. and Aged	1575°F	1050°F	15T	48-59
B-2	S.A. and Aged	1450°F	1050°F	15T	45
B-2B1	S.A. and Aged	1350°F	1050°F	15T	44
B-3	S.A. and Aged	-	1050°F + 1200°F, 20 Min., A.C.	15T	43

* All solution treatments for 20 minutes and air cooled.
** All aging for 1½ hours and air cooled.

1. All weldments showed very brittle fracture in the weld deposit.
2. Axis of bends coincided with the longitudinal centerline of the welds.

TABLE 31

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11-62

30-32 R_c, which is typical for annealed material. Age hardening of torch annealed welds produced considerably higher hardness in the weld than in the adjacent base material, and this caused brittle failure in the weld. Tensile strength data on these welds are shown in Table 32.

Resistance weldability of the alloy was evaluated. The material was readily weldable. Material used in the evaluation was fully hardened and aged prior to resistance welding. Testing was done with welds in the "as welded" condition.

The welding schedule, developed to obtain a nugget of optimum size, strength and soundness, is shown in Figure 15.

A compilation of the direct tensile strength and the tensile-shear strength of single resistance spot welded specimens is shown in Table 33. The specimens failed due to bending in the base metal. The nuggets did not shear nor fail in tension. The fractures occurred across the specimen in the base metal very close to the weld. This was the result of low ductility and fracture toughness of the base metal. Aging of the base metal to lower strength levels should be done to possibly improve this condition.

In general, this evaluation of the Ti Al-10V alloy at the maximum strength level indicated very low toughness. There were indications from the machining and processing of specimens that fracture toughness was low, even in the annealed condition.

MECHANICAL PROPERTIES OF FUSION WELDS
Ti 8Al-10V - .060 Thick Sheet
TIG Bead-On-Plate Welds

Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation % Inches ½"	1"	2"	Location of Fracture
Solution Anneal Weld	72 *	152 *	8 *	-	4.5 *	Weld *
Solution Anneal Age 1050°F, 1½ Hours	-	188	2	0.5	0.5	Weld
Solution Anneal Weld Local Torch Anneal at 1450°F.	-	114	2	0.5	0.5	Weld
Solution Anneal Weld Torch Anneal at 1450°F Air Cool	49	124	6	4	3	Weld

* Republic Steel Corporation data.

TABLE 32

MATERIALS RESEARCH LABORATORY

Resistance Welding Data Sheet

Date: 9-13-61

Project: 5017

Welding Machine	Material and Gage
Single Phase 150 KVA	Ti 8Al-10V 0.060"

Electrodes	Material Condition
5/8" dia. RWMA, Gr, A, Cl, 2, 2½" R	Solution Treated and Aged

Welding Schedule

Electrode Force, lbs.		Phase Shift, %	40 (8000 A)
Net	1500		
Forge			
Weld Cycles	10	Weld Diameter, Ins.	0.250
Impulses	1	HAZ Diameter, Ins.	0.310
Cooling Cycles	-	Penetration, %	76%
Transformer Setting	2 Series 8	Electrode Indentation, %	7%

Remarks and Special Functions:

Material grit blasted and pickled prior to welding.

Figure 15

MECHANICAL PROPERTIES

MATERIAL: Ti 8Al-10V

RESISTANCE SPOT WELDED SPECIMENS

GAGE: 0.060 INCHES

HEAT NO. 70032

SOLUTION ANNEALED AND AGED

Condition	Tensile (Type "S" Specimen) Spec. No.	Load Lbs.	Type Failure	Tensile-Shear (Type "E" Specimen) Spec. No.	Load Lbs.	Failure	$\frac{T}{TS}$ Ratio
	MUS-1	335	*	MUE-1	1620	*	
Solution Annealed	MUS-2	283	*	MUE-2	1740	*	
and Aged at	MUS-3	204	*	MUE-3	1610	*	
$1050^{o}F$, $1\frac{1}{2}$ Hours	MUS-4	290	*	MUE-4	1900	*	
	Average	278		Average	1742		0.16

* Material fractured in the base metal as the result of bending stresses. Break apparently originated in the heat affected zone of the weld.

TABLE 33

Tungsten inert gas fusion welding, using the bead-on plate technique, presented no problems in producing a sound weld. No procedure was found, however, to produce welds at a strength and ductility suitable for rocket case designs.

The material in the high strength condition is readily resistance spot welded. Low fracture toughness of the base metal hampered the evaluation. Material of greater ductility is better evaluated.

The Ti 8Al-10V alloy does not require a water quench from the solution heat treatment temperature, a significant advantage when using thin sheet or strip materials where distortion is encountered in rapid cooling.

Titanium 13V-11Cr-3Al (Ref. Report Nos. 12 and 15)

One of the most promising nonferrous alloys for possiapplication to the rocket case program is the all beta Ti 13V-11Cr-3Al alloy. This alloy has been available on the commercial market since 1958 and there has been a large amount of data gathered and distributed. Therefore, the data reported herein will only be a summary of work done at The Budd Company in the evaluation of this alloy.

Seven different heats of the alloy, in gages from .030 to .080, were received from Titanium Metals Corporation of America. The nominal composition is tabulated in Table 5.

Some physical properties of the alloy are:

Density	- 0.175 lb./cu.in.
Poisson's Ratio	- 0.304
Modulus of Elasticity	- Annealed 14.7×10^6 psi
	Aged 16.0×10^6 psi

Each heat of the Ti 13V-11Cr-3Al alloy was double vacuum melted using the consumable electrode process to control the quality of the material. Vacuum melting minimized contamination due to oxygen, hydrogen and nitrogen.

A distinct advantage of the Ti 13V-11Cr-3Al alloy is that a high temperature quench is not required. Solution annealed material may be strengthened using a simple aging treatment at temperatures between 800°F and 900°F. Solution annealing is done at 1425°F for 10 to 30 minutes, followed by air cooling. Contamination of the alloy by air at temperatures above 800°F makes the use of inert gas atmosphere a requirement for any heat treatment at or above that temperature. Aging at 900°F for periods of from 10 to 100 hours is employed, depending on the mechanical properties required.

Table 34 is a summary of the mechanical properties obtained, including center notch fracture energy tests of the evaluation made from several heats of sheet material, and employing the heat treatments shown. Aging at 16, 48 or 72 hours made small difference in the tensile values, but ductility was improved at the lower aging temperatures. Aging at 900°F was very effective in improving the strength of the

MECHANICAL PROPERTIES OF Ti 13V-11Cr-3Al

Material	Condition	0.2% Offset Yield Strength KSI	Tensile Strength KSI	% Elong. in 2"	Hardness	K_{cl} PSI $\sqrt{\text{Inch}}$	$\frac{\sigma \text{ Y.S.}}{d \times 10^6}$	$\frac{K_{cl}^2}{\pi \sigma^2 \text{ Y.S.}}$	
.060 Sheet	Annealed	L 133 T 138	135 139	23 19	$R_c 31$	-	-	-	
.080 Sheet	Annealed	L 133 T 138	134 139	21 19	$R_c 32$	-	-	-	
.030 Sheet	Cold Rolled 25%	L 152 T 155	160 172	8 8.5	$R_c 34$	-	-	-	
.030 Sheet	Cold Rolled 25% Aged 900°F 48 hours	L 200 T 212	216 223	5 2	$R_c 43$	-	-	-	
.030 Sheet	Cold Rolled 25% Aged 900°F 72 hours	L 201 T 206	217 211	4 1	$R_c 43$	-	-	-	
.032 Sheet	Cold Rolled 25% Aged 900°F 16 hours	L 199 T 209	215 222	9 5.5	$R_c 44$	-	-	-	
.060 Sheet	Annealed, Aged 900°F, 48 hours	L 183 T 185	205 206	7 4.5	$R_c 43$, 44	-	-	-	Av. of 10 Specs.
.060 Sheet	Annealed, Aged 900°F, 72 hours	L 186 T 195	188 210	6 5.5	- -	- -	- -	- -	Av. of 12 Specs.
.062 Sheet	Annealed, Aged 900°F, 72 hours	L 186 T 193	205 212	6.5 3.5	- -	70,000 45,000	1.06 1.09	.050 .024	Av. of 24 Specs.
.028 Sheet	Cold Rolled 25% Aged 900°F, 16 hours	L 199	215	9	-	72,000	1.14	.041	
.029 Sheet	Cold Rolled 25% Aged 900°F, 48 hours	L 200	216	5	-	66,000	1.14	.041	

NOTE: Specimens taken from TMCA Heat Nos. D-31, M-9583, M-9584, D-260, M-9571.

TABLE 34

The Budd Co.
10-62

alloy which had previously been cold reduced 25% to final gauge.

The fracture energy values were measured in various heat treated and cold rolled and aged conditions using the Erwin center notch specimen (Drawing 2434-0014). Relatively good K_{cl} values were measured in the longitudinal direction and these values averaged 30 to 50% higher than transverse specimens. In general, K_{cl} values were generally superior to those reported for high strength quench and temper steels at equivalent yield strength to density ratios.

A series of bend test specimens were evaluated. Results are summarized in Table 35. As would be expected, the required bend radii increased from approximately 2 X thickness in the solution annealed condition to as much as 17 X thickness at maximum yield strength.

Specimens of Ti 13V-11Cr-3Al alloy sheet in the solution annealed condition were resistance spot welded. The following types of specimens were used:

Tension Shear, Drawing 2434-0004

Cross Tension, Drawing 2434-00012

Photomicrograph - Hardness traverse

Stress Corrosion, Drawing 2434-0011

A summary of the results of tests on resistance welded specimens is shown in Table 36. These tests were made using

BEND PROPERTIES OF Ti 13V-11Cr-3Al

SPECIMENS BENT THROUGH 135° ANGLE IN CLOSED PUNCH AND DIE

Material	Condition	Direction of Specimen	Minimum "T" Ratio	Remarks
.060 Sheet	Annealed	L	2.3T	Average of 4 Specimens
		T	2.0T	
.060 Sheet	Annealed	L	8.3T	Average of 10 Specimens
	Aged 900°F, 72 hours	T	8.3T	
.084 Sheet	Annealed	T	1.5T	1 Specimen
.084 Sheet	Annealed	L	6.3T	
	Aged 900°F, 72 hours	T	6.3T	
.030 Sheet	Cold Rolled 25%	L	3.0T	
		T	3.5T	
.030 Sheet	Cold Rolled 25%	L	7.0T	
	Aged 900°F, 16 hours	T	11.0T	
.030 Sheet	Cold Rolled 25%	L	17.0T	
	Aged 900°F, 48 hours	T	17.0T	

NOTE: T = Thickness of Material

$$"T" = \frac{\text{Radius of Punch}}{\text{Thickness of Material}}$$

TMCA Heat Nos. D-31, M-9583, M-9584, M-9571, D-260

TABLE 35

MECHANICAL PROPERTIES OF

RESISTANCE WELDED Ti 13V-11Cr-3Al SPECIMENS

Material	Condition	Tensile Specimen		Tensile-Shear Specimen		$\frac{T}{TS}$ Ratio
		Load Lbs.	Type Failure	Load Lbs.	Type Failure	
.060 Sheet TMCA Heat M-9853	Annealed	3016	Plug	5061	Shear	59.5%
.060 Sheet TMCA Heat D-575	Cold Rolled 25% Age 900°F, 8 hours	2149	Fracture *	5210	Shear	41.1%

* Specimen fractured across area of weld due to bending.

TABLE 36

.060 thick sheet material. The welding schedule established for spot welding this alloy is shown in Figure 16. This alloy proved to be readily resistance weldable and nuggets were sound and reproducible. The weld nugget extends to the limit of the electrode contact diameter and there is little or no heat affected zone detectable on the metal surface and indentation is normal for the thickness of material. Microhardness surveys across the nugget indicated a relatively uniform hardness from base metal across the weld.

A similar evaluation was conducted using cold rolled material, having a reduction of 25% to final gauge. The alloy in this condition was also weldable, using the same schedule. The weld diameters were the same as for the annealed material, however, the heat affected area is more pronounced in the cold work material. Hardness traverse shows a completely annealed nugget area and with a rapid transition to base metal hardness in the heat affected zone.

There is an increase of weld strength values of the cold rolled tensile-shear specimens compared to the annealed material. Cross-tension strengths were lower (see Report No. 10 for a detailed description of specimens and method of testing). Due to the low cross-tension values, the ratio of tensile to tensile shear is lower than would be expected from cold rolled austenitic steel. This is typical for titanium alloys.

MATERIALS RESEARCH LABORATORY

Resistance Welding Data Sheet

Date: 5-4-61

Project: 5017

Welding Machine	Material and Gage
150 KVA Sciaky Single Phase Dekatron Pulse Counting	0.060" Ti 13V-11Cr-3Al (Code "E")
Electrodes	**Material Condition**
5/8" diameter RWMA, Group "A", Class 3, 2-1/2" radius	Solution Anneal and Pickled

Welding Schedule

Electrode Force, lbs.		Phase Shift, %	48
Net	1500	Squeeze Time Cycles	10
Forge	None	Hold Time Cycles	50
Weld Cycles	10	Weld diameter, inches	.234
Impulses	1	HAZ diameter, inches	.234
Cooling Cycles	None	Penetration, %	66
Transformer Setting	2 Series 2	Electrode Indentation, %	12.5

Remarks and Special Functions

Figure 16

The susceptibility of spot welds to stress corrosion was measured. The method is described in detail in Report No. 11. Two resistance spot welds were made in each specimen. The edges of the specimen were sealed with a synthetic plastic material to prevent penetration of the solution into the interfaces. Results are shown in Table 37. The annealed specimens withstood the corrosive medium of 5% and 20% concentrations of M_gCl_2 for the maximum time. The cold rolled material showed no evidence of cracking using the 5% solution. Stress corrosion cracks did appear on four specimens, subjected to the 20% concentration. Tests run with specimens having no edge seal did not indicate any increase in the severity of the experience. One small crack developed in the 78½ hour test.

Solution annealed and cold rolled .060 thick Ti 13V-11Cr-3Al alloy sheet material was T.I.G. welded using matching analysis filler wire. All weldments showed evidence of porosity of .008 to .020 inches in diameter scattered along the fusion line, as determined by radiographic inspection methods. Tensile tests were conducted on specimens taken from areas having porosity .012 inches in diameter or less. These tests produced tensile values equivalent to yield strength of annealed material. Welding schedules, to obtain penetration and adequate weld reinforcement were readily established and were reproducible. Table 38 is the weld schedule established for solution annealed material and

STRESS CORROSION DATA ON Ti 13V-11Cr-3Al
RESISTANCE SPOT WELDED SPECIMENS
SEALED EDGES

Material	*Type of Solution	Specific Gravity Start	Specific Gravity Finish	Hours	Results	Remarks
.060 Sheet Annealed	5% M_gCl_2	1.020 at 83°F	1.023 at 73°F	116	OK	4 Specimens
.060 Sheet Cold Rolled 25% Age 900°F 8 hours	5% M_gCl_2	1.020 at 83°F	1.023 at 73°F	116	OK	4 Specimens
.060 Sheet Annealed	20% M_gCl_2	1.075 at 89°F	1.078 at 90°F	126	OK	4 Specimens
.060 Sheet Cold Rolled 25% Aged 900°F 8 hours	20% M_gCl_2	1.075 at 89°F	1.078 at 90°F	126	1 Spec. cracked 74 hrs. 1 Spec. cracked 126 hrs. 1 Spec. cracked 103 hrs. 1 Spec. cracked 8½ hrs.	
.060 Sheet Cold Rolled 25% Aged 900°F 8 hours	20% M_gCl_2	1.076 at 89°F	1.082 at 89°F	78½	OK, except one Specimen showed very small crack	4 Specimens

* Boiling aqueous Solution

TABLE 37

T.I.G. FUSION WELDING SCHEDULE FOR Ti, 13V, 11Cr, 3Al, 0.060 INCH SOLUTION ANNEALED SHEET

Item		Description
Electrode		
	Type	2% thoriated tungsten
	Size	3/32", tapered point
	Stickout	3/8"
Torch		
	Type	AIRCO Model "C"
	Attack Angle	90°
	Lead angle	Zero
Root Shield		
	Type	Copper, Budd Co. dwg. E2434-0121, (see Progress Report No. 10, Figure 4).
	Groove Size	0.040" deep X 1/4" wide
	Gas ports	1/16" diameter, spaced 3/4" apart
Nozzle		
Chill Bars		Copper, 3/4" X 3-1/4" with 45° bevel to a 1/8" land
ARC Voltage		12 volts at electrode tip
DSSP Amperage		190 to 195 amperes
Shielding Gas		
	Nozzle	Argon, 25 cubic feet per hour
	Root	Argon, 3 cubic feet per hour
	Follower	Follower shield was not used
Filler Wire		
	Type	0.030" diameter, annealed beta titanium
	Feed	18" per minute.
Welding Speed		7-1/2" per minute.
Preheat-Postheat		None used.
Power Source		Vicker's, 300 ampere, rectified
Starting Mechanism		AIRCO HF-1

TABLE 38

Table 39 is the schedule for cold rolled sheet. Mechanical properties of T.I.G. welds in Ti 13V-11Cr-3Al are summarized in Table 40.

The Ti 13V-11Cr-3Al alloy is readily weldable and tensile properties of welded solution anneal sheet are essentially the same as base metal. Bend ductility is good. Tensile properties of welded cold rolled sheet are the same as annealed material, although bend ductility is slightly inferior. Schedules to obtain complete penetration welds were easily established and slight variation did not produce significant changes in the mechanical properties.

Electron beam welding of Ti 13V-11Cr-3Al alloys in both annealed and cold rolled and aged conditions was evaluated. All welds were made using a high voltage electron beam welding machine at Bristol Machine and Tool Company, Forrestville, Connecticut. A special welding fixture adapted to the welding machine was used. All weldments were radiographically inspected and test specimens were located on the weldment in areas where porosity did not exceed .020 inch diameter.

One of the characteristics of electron beam welds is the narrow weld and heat affected zone. On the .060 Ti 13V-11Cr-3Al alloy, the average weld width on the applied side was .068 and on the penetration side was .025 inches. Maximum width of weld, plus heat affected zone, was approximately .100 inch or an average of 1½ X thickness.

T.I.G. FUSION WELDING SCHEDULE FOR Ti, 13V, 11Cr., 3Al 0.060 INCH SHEET COLD ROLLED AND AGED TO 230 KSI U. T. S.

Electrode	
Type	2% thoriated tungsten
Size	3/32, tapered point
Stickout	3/8"
Torch	
Type	AIRCO Model "C"
Attack angle	90^{o}
Lead angle	Zero
Root Shield	
Type	Copper, Budd Co. dwg. E2434-0121 (See Progress Report No. 10).
Groove size	0.040" deep X 3/16" wide.
Gas ports	1/16" diameter, spaced 3/4" apart
Chill Bars	Copper, 3/4" X 3-1/4:, with 45^{o} bevel to a 1/8" land.
Nozzle	Metal, 5/8" diameter
ARC Voltage	12 volts at electrode tip.
DSCP Amperage	180 to 190 amperes.
Shielding Gas	
Nozzle	Argon, 30 cubic feet per hour
Root	Argon, 3 cubic feet per hour
Follower	Follower shield was not used
Filler Wire	
Type	0.030" diameter, annealed beta titanium
Feed	18" per minute.
Welding Speed	7-1/2" per minute
Preheat-Postheat	None
Power Source	Vicker's 300 amperes rectified
Starting Mechanism	AIRCO HF-1

TABLE 39

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MECHANICAL PROPERTIES - Ti 13V-11Cr-3Al

T.I.G. WELDED SPECIMENS

Material	Condition	0.2% Yield Strength KSI	Tensile Strength KSI	Elongation % 2"	Elongation % 1/2"	Location of Fracture	Remarks
.060 Sheet TMCA Ht. 9853	Annealed Welded	134	136	17	-	Base Metal	Average of 4 Specimens
	Annealed Welded Reinf. Removed	134	137	21	42	HAZ	Average of 4 Specimens
.060 Sheet TMCA Ht. D575	Cold Rolled 25% Aged Welded	160	163	2.5	12	HAZ	Average of 4 Specimens
	Cold Rolled 25% Aged Welded Reinf. Removed	130	134	3.5	14	Weld Deposit	Average of 4 Specimens

TABLE 40

Table 41 is a summary of mechanical properties obtained from electron beam welds. Welds oriented 90° - 40° and 20° to centerline of specimen were tested. Solution annealed base metal, welded, with the weld in the "as welded" condition exhibited a uniform necking and ductility with the fracture occurring in the base metal away from the heat affected zone. Age hardening the weld resulted in practically no deformation and failure occurred in the very brittle cold metal. Welding of cold rolled and aged material resulted in specimen having removable strength and measurable ductility.

Orientation of the weld line at 20° and 40° to normal weld line and its effect on properties was studied. It was determined that a 20° angle of weld in combination with cold rolled and aged material produced the highest specimen ultimate strength (185 ksi).

ALLOY SELECTION FOR THE 20 INCH TEST CASES

The principal outcome of the materials search and evaluation was the selection, from the 12 alloys studied, of two whose properties appeared to fit into the design concept. Specific requirements of the materials became more apparent as the design details were developed. This design consists of a helical fusion welded cylinder with the weld line oriented 11° to a circumferential line on the cylinder. Closures are welded to this cylinder using a single girth weld. The stress in the helical weld is only slightly more than one-half the hoop stress in the cylinder, due to the two to one stress field. The helical weld

MECHANICAL PROPERTIES - ELECTRON BEAM WELDMENTS
Ti 13V-11Cr-3Al ALLOY
.060 THICK SHEET

Condition	Tensile Strength KSI	Elongation - % in 2"	1"	½"	¼"	Weld Angle	Location of Fracture
Solution Anneal Weld Aged	162	B R I T T L E				90°	Weld
Solution Anneal Weld	140	9	6	4	4	90°	Base Metal
Cold Rolled Aged Weld	146	3	5	12	28	40°	Weld
Cold Rolled Aged Weld	187	4	7	8	8	20°	Base Metal
Cold Rolled Aged Weld	155	-	3	-	-	90°	Weld
Cold Rolled Aged Weld Aged Stress Relieve	185	1½	-	2	4	90°	Weld

TABLE 41

yield strength, including safety factor, may be 60 to 70% of the base metal yield strength.

With these requirements it has been necessary to eliminate from the program all materials which are hardened by cold rolling and aging. Welding of this type of material produces an annealed weld area of low strength and there is no practical means of restoring the weld strength by thermal treatment or by mechanical processing.

Others have been eliminated on the basis of low strength to density ratios compared to competitive alloys.

The alpha-beta titanium alloys were not given further consideration due to low weld strengths and any attempt to improve the properties by thermal treatment resulted in a highly brittle condition. It was also questionable that these alloys would be commercially available in sheet and strip form within the timing of the program.

Hot-cold worked alloys considered are only in preliminary stages of development, and processing procedures have not been standardized. In addition, they will not be commercially available for some time, although their properties show considerable promise for the future.

The two materials which most closely meet the requirements of our rocket case design are the 20% nickel mar-aging steel and the all beta titanium alloy Ti 13V-11Cr-3Al.

Using the 20% nickel mar-aging steel, it is possible to attain satisfactory base metal strengths by cold reduction and aging, or by

heat treatment alone. The annealed condition caused by welds reduces the weld yield strength to about 35% of the base metal yield strength. However, using selected aging treatments, it is possible to increase the weld strength to about 70% of the maximum base metal yield strength. It is also possible to establish compatible heat treat procedures to develop adequate strength in the various components of the case, even though the parts have had different process histories.

The Ti 13V-11Cr-3Al alloy has sufficiently high strength in the "as welded" condition to meet the requirement that weld yield strength be 60 to 70% of the base metal yield strength. No subsequent heat treatment is required after welding.

Both the 20% nickel mar-aging steel and Ti 13V-11Cr-3Al alloy are available in strip and sheet form from several sources.

In summary, the 20% nickel mar-aging steel and the beta titanium alloy were selected for the reasons listed below:

1. They are capable of attaining a strength/density ratio of 1 X 10^6 inches or higher.

2. They are weldable by T.I.G., electron beam, and resistance spot welding process.

3. The weld strength is adequate either in the "as welded" condition or the strength can be increased by simple thermal treatments to a satisfactory level with reasonable ductility.

4. The heat treatments for both alloys are simple, consisting of a single aging cycle at moderate temperatures.

5. Quenching is not required as a part of the thermal processing.

6. Both materials are dimensionally stable when heat treated. There are no phase transformations to produce significant dimensional changes.

7. Both alloys are commercially available in suitable product forms.

UNIAXIAL WELD JOINT EVALUATION - AM-355 - PH-15-7 Mo MATERIAL (Ref. Reports Nos. 6 and 12)

Hydrotest of 65 inch diameter test chambers on a previous contract employing a double wrapped resistance welded cylindrical section of cold rolled AM-355 material, and a formed elliptical head of PH 15-7 Mo material, indicated the need for closer examination of the head to shell joint, plus the joint connecting cylindrical segments. Failure in these test chambers occurred in the head to shell joints.

Analysis of these failures revealed that the reinforcing doublers did not carry the membrane loads from the closure to the shell due to the inadequacy of the spot weld pattern in the weld reinforcing doublers.

Since this design was among those under consideration in the early stages of this program, it was decided, in conjunction with the Technical Supervisor, Frankford Arsenal, to test a series of uniaxial specimens which would simulate the joint conditions.

Particular attention must be given to the joints in the design which employed materials which gain strength by strain hardening, as a result of cold rolling. The strength gained in the cold rolling is lost in the weld area. The weld is annealed and at a relatively low strength, and therefore it must be reinforced to carry even the membrane loads. The reinforcements introduce discontinuity stresses. The strength of each joint is also dependent on the load distribution between the main shell and the reinforcing doublers, and therefore the strength afforded by the welds, both fusion and spot, have a definite effect on joint efficiency. The joint efficiency is also sensitive to asymmetry along the fusion welded joint. It is difficult to make a fusion weld with a straight edge; however, a seam resistance weld can be controlled more closely in this area. We therefore processed several different combinations of fusion and resistance weld arrangements, namely:

1. A single row seam weld through all sheets prior to fusion welding.
2. A double row of seam welds through all sheets prior to fusion welding.
3. A double row of seam welds, followed by flame anneal prior to fusion welding.

4. A single row of seam welds through all sheets and a second row through doublers and main shell individually.

A series of nine design configurations were fabricated in accordance with drawings listed below, copies of which were included in Reports Nos. 6 and 12:

B-480-SK-0007 - Shell to Shell Segment Joint.

B-480-SK-0008 - Head to Shell Joint, Double Seam Weld, Flame Anneal.

B-480-SK-0009 - Head to Shell Joint, Double Seam Weld, Unsymmetrical Pattern of Spot Welds.

B-480-SK-0010 - Head to Shell Joint, Double Seam Weld, Spot Welds Through Full Pileup of Doubler and Shell.

B-480-SK-0011 - Head to Shell Joint, Double Seam Weld.

B-480-SK-0012 - Head to Shell Joint, Single Seam Weld.

B-480-SK-0013 - Head to Shell Joint, Double Seam Weld, Unsymmetrical Arrangement of Doublers.

B-480-SK-0014 - Head to Shell Joint, Double Seam Weld, Unsymmetrical Arrangement of Doublers.

B-480-SK-0015 - Head to Shell Joint, Double Seam Weld, Unsymmetrical Arrangement of Doublers.

One of the problem areas associated with joining multiple wrapped cylinders to closures by welding is contamination at the interfaces during welding. The seam welds served two main purposes:

1. To seal the interface areas to prevent contamination during subsequent fusion welding.

2. To provide an increased annealed area to partially offset discontinuity stresses resulting from variations in fusion weld edge.

The material selected for the cylinder simulation specimen was AM-355 in the SCCRT (sub-zero cooled, cold rolled, tempered) condition. The tensile strength was 290,000 psi. The closure simulation was PH 15-7 Mo in the RH-1050 condition and the tensile strength was 220,000 psi.

The specimens were tested and examination of the failure showed good correlation with the case failure experienced and pointed to specific revisions in the design of shell closure joints.

The following conclusions on the designs are made:

1. The number of spot welds must be increased and/or the doublers size must be increased. In every case the spot welds sheared before the fusion welded joint failed. This was similar to the condition experienced in the case test.

2. The double row of seam welds through the pileup of shell and doubler provided the

maximum overall ductility in the joint.

3. The designs represented by Drawings B-480-0009 and B-480-0010 appeared to be the most desirable.

The results of these tests are summarized in Table 42.

20 INCH DIAMETER TEST CASE

The evaluation and selection of two alloys, 20% nickel mar-aging steel and beta titanium, was made. Design of a specific test case utilizing the properties of the materials was undertaken.

The decision was made to concentrate the effort on a 20 inch test chamber using 20% nickel mar-aging steel. This was with the concurrence of the Technical Advisor at Frankford Arsenal.

There are many possible design arrangements for a cylindrical section using thin sheet or strip materials. A qualitative evaluation was made of several designs considering process techniques, material properties, toughness of the materials, and weld properties. An order of merit number was assigned to each consideration for each design. From these studies it was evident that a cylindrical section, which would operate at a maximum strength to density ratio, must have the following characteristics:

1. The base metal yield strength to weight ratio must be slightly higher than the ratio desired in the case to offset the

AM 355, PH 15-7 MO UNIAXIAL WELD JOINT DESIGN
COMPARISON OF JOINT EFFICIENCIES, FRACTURES
AND FAILURE LOCATION

Specimen No. B480-SK-	Unit Failure Load*	Joint Efficiency**	Maximum Strain in/in.	Location of Initial Fracture	Location of Joint Failure
-0007	30,500	92	.0256	Sheared Spot Welds	Outer Seam Weld HAZ
-0008	28,900	87	.0125	Sheared Spot Welds Doubler to PH 15-7 Mo Plate	Fusion Weld
-0009	35,600	107	.0132	Sheared Spot Welds Doubler to PH 15-7 Mo Plate	Fusion Weld HAZ in PH 15-7 Mo Plate
-0010	35,900	108	.0212	Sheared Spot Welds Doubler to PH 15-7 Mo Plate	Fusion Weld HAZ in PH 15-7 Mo Plate
-0011	23,650	70	.0162	a) Sheared Spot Welds in Shell Plate Assembly	a) Spot Weld in Doubler to Shell Plate
				b) Sheared one Plate of double thickness Shell Plate Assembly from Fusion Weld	b) Outer seam weld HAZ D
-0012	25,200	76	.0056	Sheared Spot Weld in Doubler to Shell Plate Assembly	Seam Weld HAZ
-0013	33,700	102	.0194	Sheared Spot Weld in Doubler to Shell Plate Assembly	Inner Seam Weld HAZ

TABLE 42 (Continued)

AM 355, PH 15-7 MO UNIAXIAL WELD JOINT DESIGN COMPARISON OF JOINT EFFICIENCIES, FRACTURES AND FAILURE LOCATION

Specimen No. B480-SK-	Unit Failure Load*	Joint Efficiency**	Maximum Strain in/in.	Location of Initial Fracture	Location of Joint Failure
-0014	37,000	111	.0188	Tensile Failure Outer Spot Weld in Doubler to Shell Plate Assembly	At First Fracture
-0015	26,200	79	.0100	Sheared Spot Welds Doubler to Shell Plate Assembly	Inner Seam Weld HAZ

* Pounds per linear inch of fusion weld.

** Joint efficiency based on strength of two sheets with 1.20" field weld spacing. This represents the basic sheet as shown in the joint design stress analysis, Appendix F, Quarterly Report No. 6. Joint efficiencies greater than 100% indicates that the stress analysis is conservative.

NOTE: All specimens had an 8 inch gage length with extensometer mounted beyond the doublers.

TABLE 42 (Continued)

effect of production variables and design discontinuities.

2. The material must have a high annealed weld strength to reduce the need for severe post weld heat treatments or strain hardening of weld areas. The design should avoid where possible the need for weld reinforcement, such as local upsetting at edges or doublers.

3. The material must have the highest possible fracture toughness at the selected strength level.

4. Dimensional discontinuities must be kept to a minimum.

Four possible designs of cylindrical section are illustrated in Figure 17. These include: rolled and longitudinal butt welded sheet; helical butt welded strip; chevron butt welded sections joined by circumferential girth butt welds; overlapping resistance welded joint with welds in a chevron pattern. Any design using sheet or strip material involves welding and the weld properties are a limiting factor in the overall strength of the case. In the case of a cylinder having a single longitudinal butt weld, the weld is subjected to the maximum hoop stress in the cylinder. It is necessary, therefore, to either design the case to operate at the attainable weld strength, or provide a means of reinforcing the joint, which is a weight and manufacturing

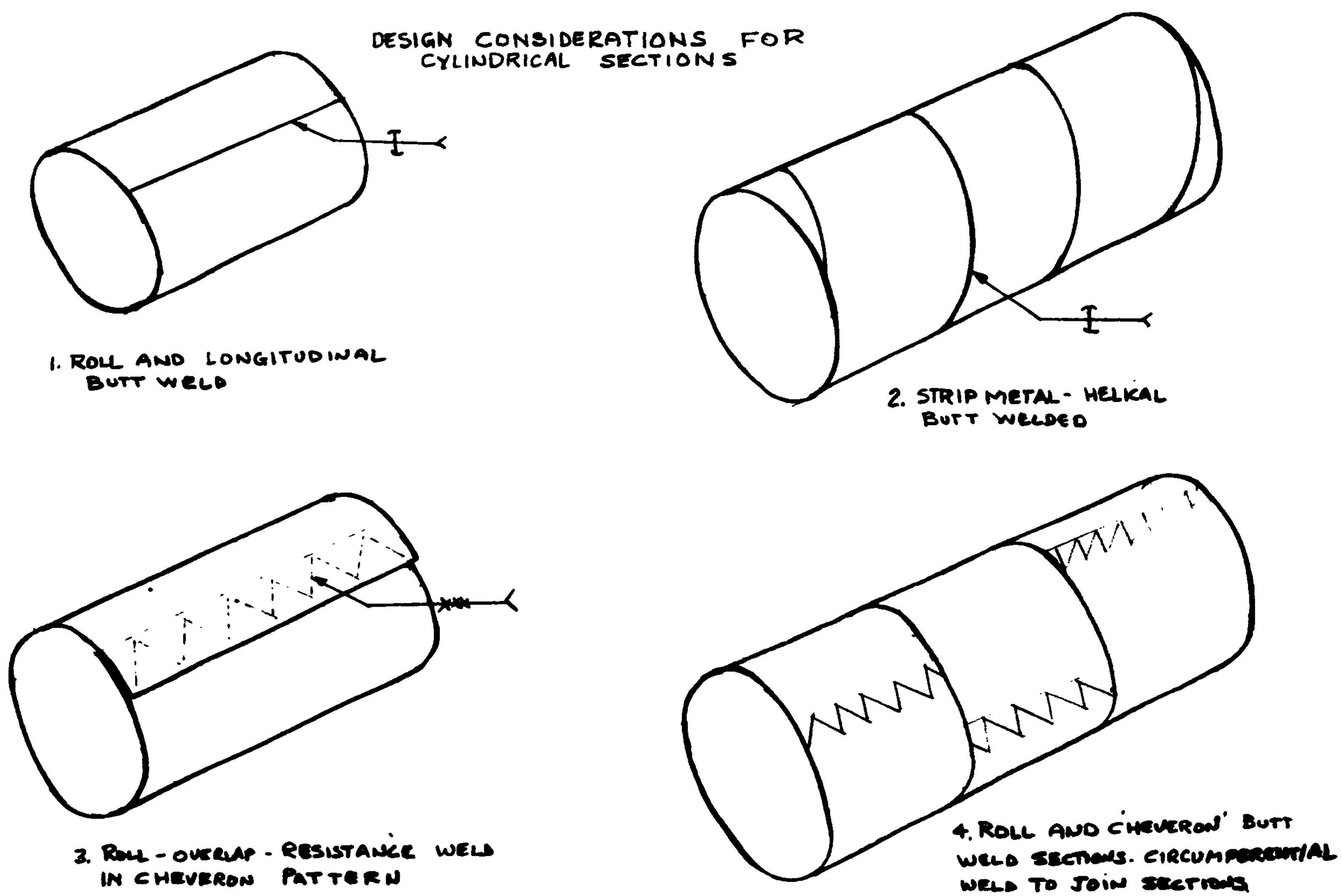
DESIGN CONSIDERATIONS FOR CYLINDRICAL SECTIONS
1. ROLL AND LONGITUDINAL BUTT WELD
2. STRIP METAL - HELICAL BUTT WELDED
3. ROLL - OVERLAP - RESISTANCE WELD IN CHEVRON PATTERN
4. ROLL AND 'CHEVRON' BUTT WELD SECTIONS. CIRCUMFERENTIAL WELD TO JOIN SECTIONS

Figure 17

penalty. In the other design considerations shown, the stresses in the welds are reduced by orienting the weld line, in the biaxial stress field, to a position that the full strength of the base metal can be developed.

In order to determine the proper orientation angle, a series of uniaxial weld test specimens were prepared. Weld angles of 90^{o}, 40^{o} and 20^{o} to the line of load application were used. From these data, it was determined that an angle of 20^{o} or less would reduce the stress in the weld of a given alloy to the point where failure would occur in the base metal across the weld where weld strengths of 60 to 80% of the base metal yield strength were attained.

The detailed analysis of the interrelation between base metal yield strength, weld strength and weld line orientation angle is covered in Report No. 18.

Based on these studies, a cylindrical section having a preferentially oriented helical butt weld was selected for the 20 inch test case. Some of the principal reasons for this selection are:

1. Strip materials are available in the alloy selected, having a sufficiently high yield strength to satisfy the design objectives.

2. The penalties imposed by discontinuities resulting from lap joints or doubler reinforcements are reduced or eliminated.

3. The connection of the head to the cylindrical section is simplified by eliminating the necessity of joining a multilayer cylinder to the head.

4. Preferential orientation of the weld line reduces the normal stress sustained across the weld line.

5. Proven and available process techniques can be employed in the fabrication of this design of cylindrical section.

The design of test case, including an overstrength elliptical head and a test aft closure is shown in Figure 18, Drawing B2434-0169. The effective length of the cylindrical section is 40 inches, which is twice the diameter.

An overstrength 1.4:1 elliptical head is employed in the case design to test the weld joining the head to the cylinder. An integral cylindrical section three inches long is formed with the head so that the girth weld will be out of the area of maximum bending. A gradual taper is provided in the cylindrical section of the head to match the cylinder thickness.

The cylinder was made from .040 thick, 20% nickel mar-aging steel, heat No. 24022 Allegheny-Ludlum, cold rolled 60% to final gage, and aged to a yield strength of 300,000 psi. The coil width is 11-7/8 inches. The elliptical head was drawn at room temperature from annealed

DO NOT SCALE DRAWINGS

REPORT ALL CHANGES AND ER

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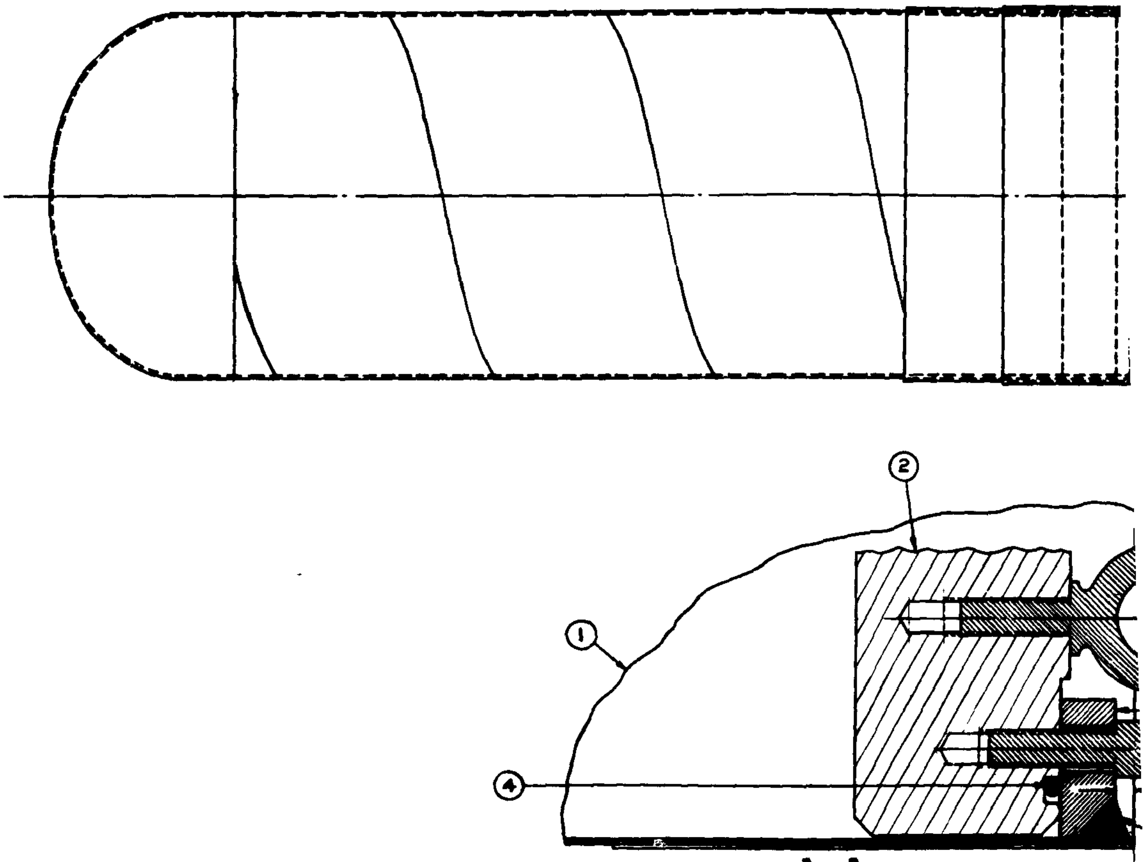


SEC. A-A (SCALE 1:1)

ROTATED 90° CLOCKWISE

DO NOT SCALE DRAWINGS REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT

2

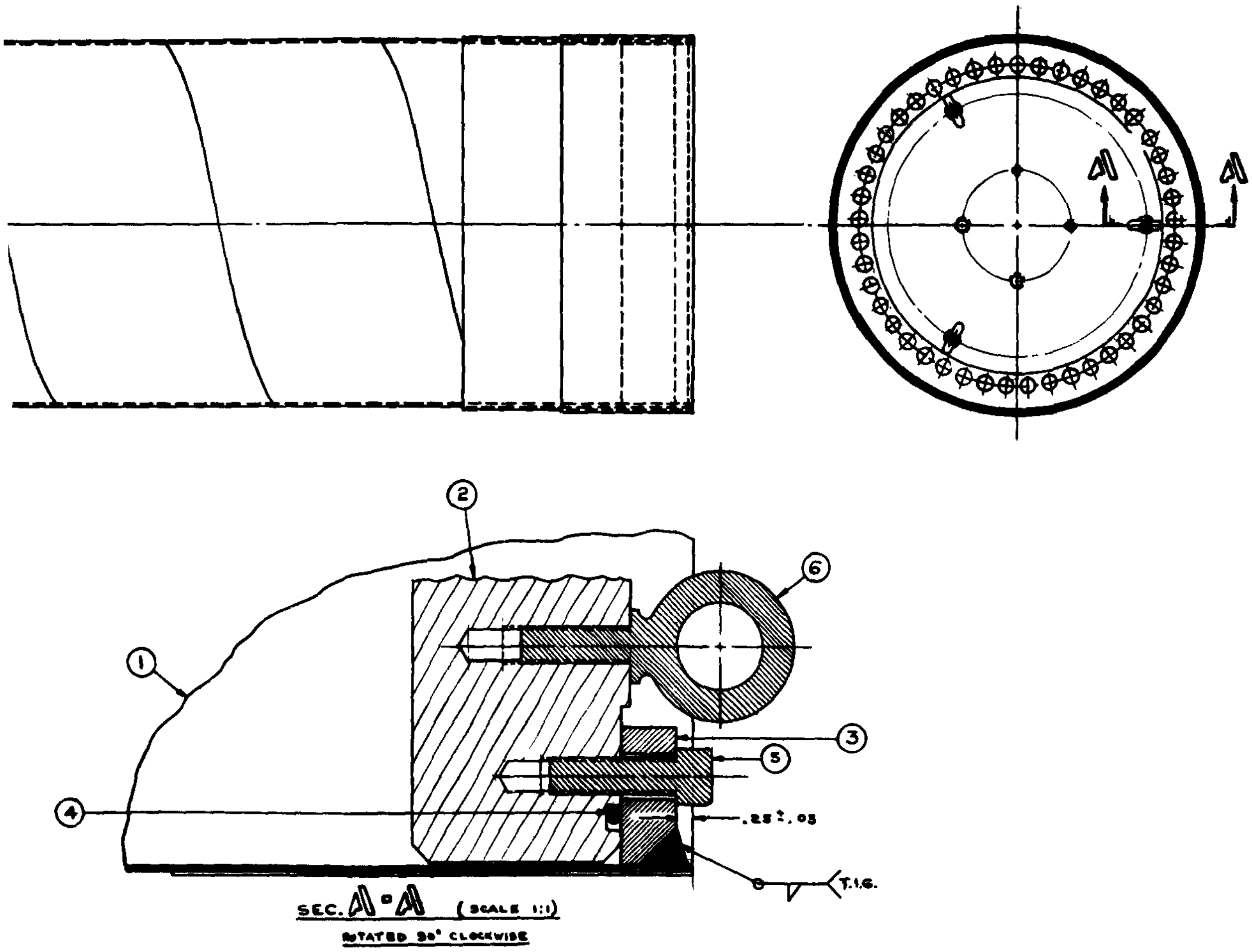
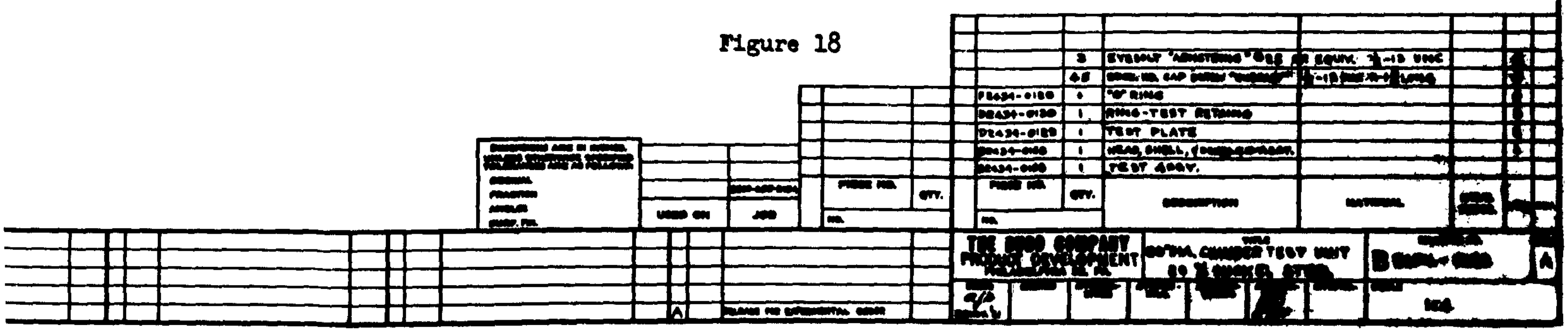


Figure 18



20% nickel mar-aging steel, same heat as the cylinder.

Figure 19 is a summary of the principal stresses, calculated for the 20 inch mar-aging steel case. The properties of the base metal and welds are shown for comparison.

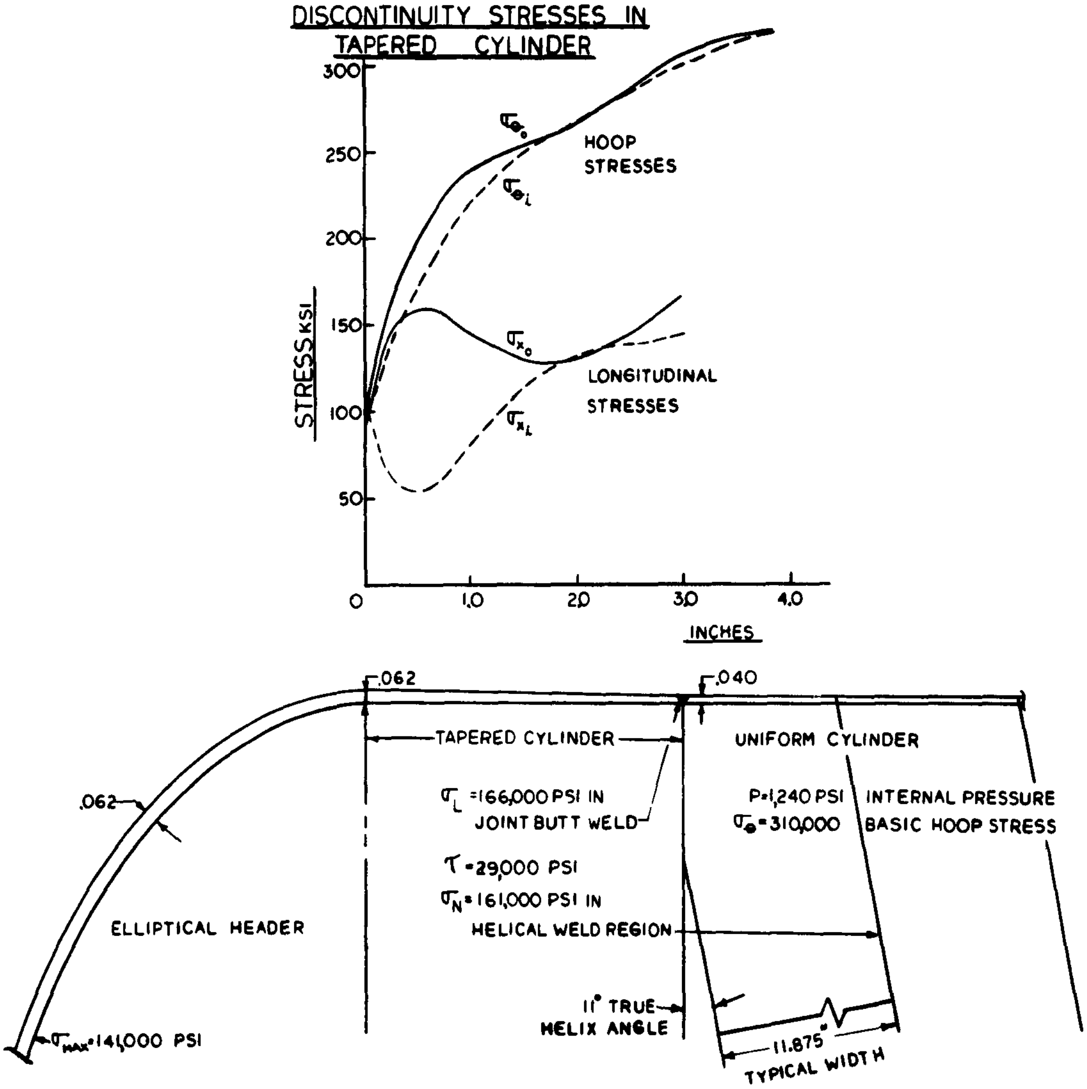
MANUFACTURING OF 20 INCH DIAMETER TEST CASES

The fabrication of the 20 inch diameter test cases to the selected design was undertaken. The three principal components in the test case are: The cylindrical section; the elliptical head; and the assembly of the cylinder and head. The fabrication development will be discussed in that sequence.

Cylindrical Section

The feasibility of welding high strength strip material into a cylinder was developed on a rigged-up fixture. This fixture is shown in the photograph Figure 20. Strip six inches wide, .020 thick type 301 stainless steel was used. A ten inch diameter cylinder was made with the weld line oriented 11° to a circumferential line. The 11° angle was selected on the basis of geometry as the controlling item, in order to keep the coil widths within reasonable and attainable limits. The coil stock is fed into the support shoes at the 11° angle by means of driven pinch rolls. The shoes, which served to align the strip for welding, were machined to the exact radius of the cylinder with only enough clearance to allow the strip to pass without binding. The cylinder diameter is initially established by

20" DIAMETER TEST CHAMBER
20% NICKEL STEEL
SUMMARY OF PRINCIPAL CALCULATED STRESSES AND MAT'L PROPERTIES



	ANNEALED	ANNEALED SUB-ZERO COOLED AGED	COLD ROLLED	COLD ROLLED SUB-ZERO COOLED AGED	AS WELDED	WELD SUB-ZERO COOL'D AGED
Y.S.	130,000	290,000	170,000	310,000	125,000	225,000
T.S.	170,000	310,000	240,000	315,000	170,000	245,000
EL.	8 %	3 %	6 %	3 %	–	–
R_c	34	58	42	58	–	–

Figure 19

DWG.NO. 2434-0223

Welding Fixture for
10 Inch Diameter Cylinders

Figure 20

means of a plug over which the strip is wrapped and tack welded. The T.I.G. welding takes place at the point of tangency where the incoming strip joins the already tack welded cylinder. Several ten inch cylinders, several feet long, were made using this fixture and the technique was determined to be satisfactory. Beta titanium (Ti 13V-11Cr-3Al) strip was welded successfully in addition to the stainless steel.

A welding fixture was then designed and built, employing the same principles used on the ten inch unit, to fabricate 20 inch diameter cylinders. This fixture is illustrated in Figures 21 and 22. This fixture was designed specifically for the 20 inch case. Strip stock .040 inches thick X 12 inches wide is fed into the cylinder by means of pinch rolls. The rolls are driven through a gear reducer by a variable speed motor. T.I.G. welding is done at the point of tangency where the incoming strip joins the formed cylinder through an opening in the casting. Cover gas is supplied by means of a manifold attached to the cylinder parallel to the weld line. Backup gas is supplied through a copper shoe, which also serves to align the strip for welding and provide chill. Water is supplied to this shoe to increase the chill effect. Accurate guidance of the strip passing through the pinch rolls is maintained by means of bronze shoes and a pressure plate. Slight lateral adjustment of the side

Helical Welding Fixture Showing Relation
of Welding Head and Backup Shoe.

Figure 21

Helical Welding Fixture
Arrangement of Drive Rolls
20 Inch Diameter Cylinders

Figure 22

guide shoes and rolls is provided to compensate for variations in coil width and camber. This control is monitored by the welding operator, who can visually determine any change in gap, mismatch or other variables and signal for correction to the operator monitoring the feed controls.

The welding schedule established for the 20 inch diameter, .040 inch thick, 20% nickel steel cylinder is shown in Table 43.

Two cylinders were welded and welds were examined visually and by means of florescent penetrant inspection at Material Testing Laboratories in Philadelphia to detect any surface defects. The welds were found to be sound. The welds were then radiographically inspected in The Budd Company Materials Research Laboratory and all welds were well within acceptable limits. In fact, the welds made in the 20% nickel mar-aging steel strip were unusually free from internal defects when compared to our welding experience in stainless steel and other alloys.

After welding, the cylindrical section was sub-zero cooled, and aged to increase base metal and weld strengths to the requirements of the design. Control specimens taken from an extension of the cylinder, which were welded at the same time and under the same conditions, were attached. Control specimen test results are summarized in another section of this report.

T. I. G. WELDING SCHEDULE
20% NICKEL MAR-AGING STEEL
ALLEGHENY-LUDLUM HEAT 74022
.040 THICK X 12 INCHES WIDE COIL
20 INCH CYLINDER HELICAL WELD IN FIXTURE

Weld Current	50 Amperes D.C.S.P.
Arc Voltage	9 Volts
Weld Travel	7 Inches/Minute
Weld Wire Feed	15 Inches/Minute
Torch Gas	Argon - 20 C.F.H.
Trail Gas	Argon - 10 C.F.H.
Backup Gas	Helium - 11 C.F.H.
Electrode	3/32 Diameter Thoriated Tungsten, Tapered to 1/32 in ¼ inch length
Arc Length	3/8 inch to ½ inch
Backup Groove	.050 inches deep X ¼ inch wide
Weld Wire	.030 Diameter Allegheny-Ludlum Heat 7-C-088. 20% Nickel Steel, Matching Analysis

TABLE 43

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Elliptical Head Fabrication

One of the areas of the helical welded 20 inch test case where proof of the design was desired was the welded joint between the cylindrical section and closure. The intersection of the girth weld and helical weld was of particular concern.

A membrane closure, which would be sufficiently overstrength to ensure failure in the weld joint and not in the head, was included in the test case design. The girth weld was located three inches from the area of maximum bending stress in the head. An integral cylindrical section formed on the head three inches long was therefore required. The .062 thickness of the head was tapered to .040 to match the cylinder thickness. The taper was extended over the three inch length.

The fabrication development for forming an elliptical head was accomplished in two steps: first by forming ten inch hemispheres, and second, using the experience gained from the ten inch heads to form the 20 inch elliptical heads. The 20% nickel mar-aging steel in the annealed condition has an elongation in 2 inches of 8% to 9% so that conventional drawing methods would be unsatisfactory.

The initial attempt to form ten inch diameter hemispherical heads was made using a conventional punch and

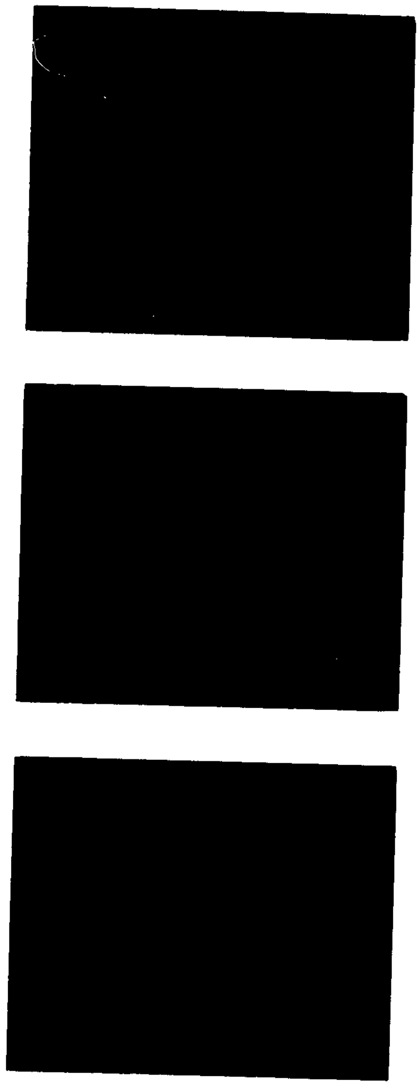
draw ring die on a 750 ton double action hydraulic press. The material was .020 inch thick 20% nickel mar-aging steel in the annealed condition. In every case the heads ruptured during forming. The results are shown in photographs in Figure 23. A .040 low carbon body steel sandwich cover plate was applied to each stamping. The thickness of the sandwich cover plate was insufficient to support the low elongation material during forming and the parts ruptured.

A series of blanks were then prepared using .034 inch thick 20% nickel mar-aging steel, together with .190 inch carbon steel sandwich cover plates. The same die and press were used to form the heads. The draw ring diameter was increased to compensate for the increased overall thickness. One head out of seven was satisfactorily formed which indicated that additional support was required. These tests did provide sufficient data to support our estimates on requirements for forming 20 inch elliptical heads. Figure 24 illustrates the 20% nickel hemispherical heads ten inches in diameter, made on the second attempt.

The same sandwich forming technique was carried over into the fabrication of the 20 inch diameter, 1.4:1 elliptical heads made from 20% nickel mar-aging steel. Figure 25 shows the arrangement of sandwich panels used in the blank and after forming. Six heads were formed from .062 - 20% nickel mar-aging steel with a finished part yield of 100%. The heads were formed at room temperature on an 850 ton

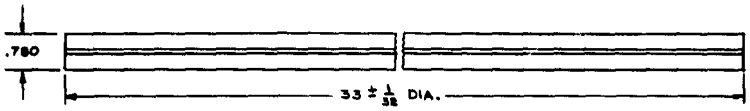
10 Inch Diameter Hemispherical Heads
20% Nichel Mar-Aging Steel
Beta TI 13V - 11CR - 3AL
0.040 Carbon Steel Cover Plates

Figure 23

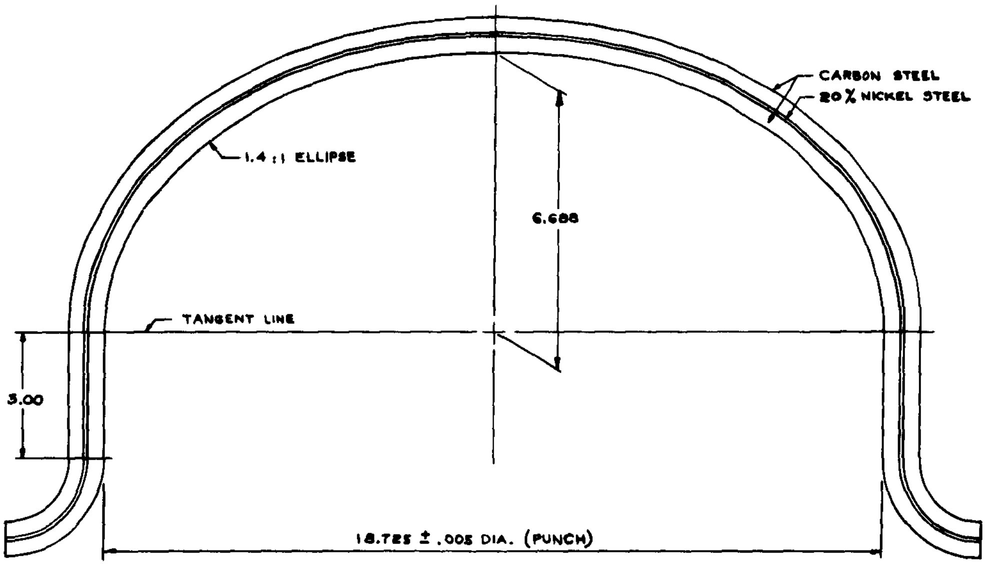


10 Inch Diameter Hemispherical Head
20% Nickel Mar-Aging Steel
.190 Thick Carbon Steel Cover Plates

Figure 24



PREPARED SANDWICH BLANK



ARRANGEMENT OF SANDWICH BLANK FOR
FORMING 20" DIA., 1.4:1 ELLIPTICAL HEAD

Figure 25

double action hydraulic press. Figure 26 is a photograph of these heads prior to final trim and taper. Excellent dimensional control was possible; thickness variations did not exceed 10% of the nominal thickness.

Control of the diameters of the elliptical heads and the effect of various heat treat cycles was of particular concern, since this diameter must match the cylinder for welding. In general, a reduction in diameter, on a .065 thick 20 inch head, of .050 to 060 was experienced as a result of solution annealing and also aging. After solution anneal, it was necessary to over-size the diameter slightly less than this amount. After aging a very limited sizing was required to fit head to cylinder. Table 44 is a summary of dimensions taken on the outside diameter of the cylindrical section of the heads and shows the effect of various process elements.

As in the case of the cylindrical section, control tensile specimens were attached to each head during all thermal treatments. This data is reported elsewhere in the report.

Head serial Nos. NH-1 and NH-2 were scrapped due to an error in the solution anneal heat treatment which caused them to be under-strength in response to aging. Heads Nos. NH-3 and NH-4 were used on the test cases. Nos. NH-5 and NH-6 were spares.

20 Inch Diameter 1.4:1 Elliptical Heads
.062 Thick 20% Nickel Mar-Aging Steel
Drawn at Room Temperature

Figure 26

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12-62

20 INCH DIAMETER, 1.4:1 ELLIPTICAL HEADS
EFFECT OF PROCESSING ON DIAMETER (PI TAPE)
20% NICKEL MAR-AGING STEEL

Condition	OUTSIDE DIAMETER OF CYLINDRICAL SECTION					
	Serial No. NH-1	Serial No. NH-2	* Serial No. NH-3	* Serial No. NH-4	Serial No. NH-5	Serial No. NH-6
As Formed	19.700	19.700	19.731	19.741	19.735	19.745
Solution Anneal 1500°F., 1 hr.	19.657	19.653	19.592	19.580	19.612	19.600
Trim Flange	19.640	19.643	19.616	19.600	19.612	19.600
-100°F., 16 hrs.	19.640	19.640	19.616	19.600	19.612	19.593
Sized To	19.740	19.773	19.792	19.785	19.753	19.772
Age 900°F., 3 hrs.	19.678	19.697	19.730	19.725	-	-
Re-Solution Anneal	-	-	19.660	19.638	-	-
Re-size	-	-	19.725	19.744	-	-
Re-age	-	-	19.671	19.770	-	-

* Used on Test Cases.
All Dimensions taken at room temperature.

TABLE 44

Assembly - Final Test Case

Fabrication of the cylindrical section and elliptical closure was completed. The closure was then welded to the cylinder. This joint was made in an internal expanding type fixture attached to a precision welding positioner. Restraint on the parts could be adjusted by means of a mechanical screw and linkage tied to the segmented backup shoes. The welding schedule established for this joint is shown in Table 45. Experience in welding the mar-aging steels has indicated that restraint of the parts in fixtures should be at a minimum. In welding the head to the cylinder, it was necessary to ease the restraint of the fixture to a considerable degree to avoid centerline cracking in the weld. To maintain a good dimensional relationship in the weld, particularly mismatch, a series of manual tacks approximately two inches apart were used. This was followed by a light manual pass with no filler wire or penetration. The complete girth weld was then made using automatic equipment with full penetration. This provided a good quality weld with a minimum of dimensional variations. Multiple pass welding apparently has no degrading effect on weld properties. Figure 27 is a photograph of the 20 inch diameter case in the fixture on completion of the head to shell girth joint.

Figure 28 schematically illustrates the heat treat processing sequence used in the manufacture of the 20 inch test case and the nominal strength of base metal and welds.

T. I. G. WELDING SCHEDULE
20% NICKEL MAR-AGING STEEL
HEAD TO CYLINDER GIRTH WELD

Weld Current	55 Amperes D.C.S.P.
Arc Voltage	8½ Volts
Weld Travel	6 Inches/Minute
Weld Wire Feed	15 Inches/Minute
Torch Gas	Argon 30 C.F.M.
Backup Gas	Helium 20 C.F.M.
Electrode	3/32 Diameter Toriated Tungsten, Tapered to 1/32 in ¼ inch length
Arc Length	¼ to 3/8 inches
Backup Groove (in Fixture T2434-0217)	.060 inches deep X ¼ inch wide
Weld Wire	.030 Diameter - Allegheny-Ludlum Heat 7-C-088. 20% Nickel Steel Matching Analysis.

Notes: Prior to automatic welding, the following process was used:

1. Setup head and cylinder in Fixture T2434-0217.
2. Manual tack each two inches of circumference; 80 C.F.M. Helium Backup Gas.
3. Manual weld entire circumference; no filler metal or penetration. Minimum possible restraint on fixture to ensure alignment of parts.
4. Automatic weld as per schedule above.

TABLE 45

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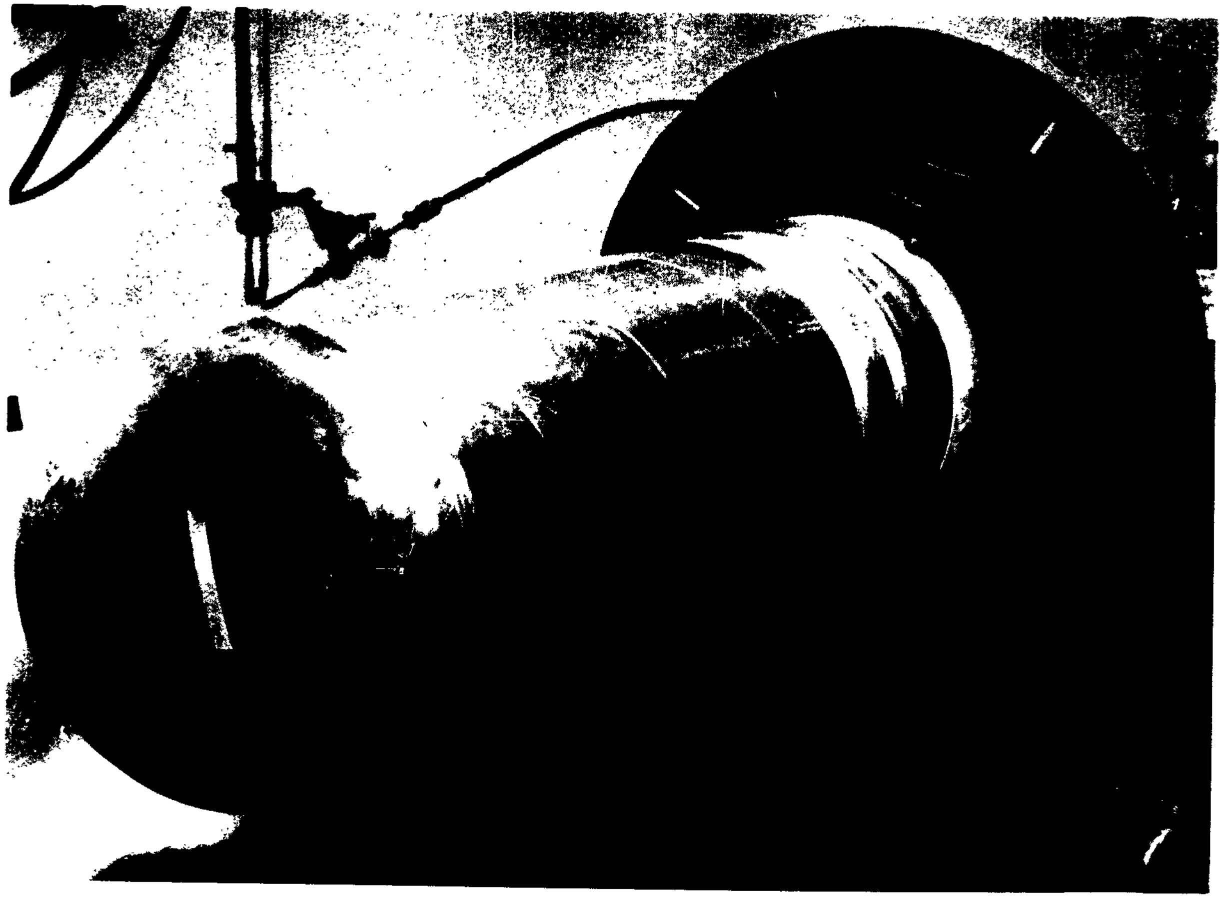


20 Inch Diameter x 60 Inch Long Test Case
Mounted in Girth Welding Fixture
20% Nickel Mar-Aging Steel

Figure 27

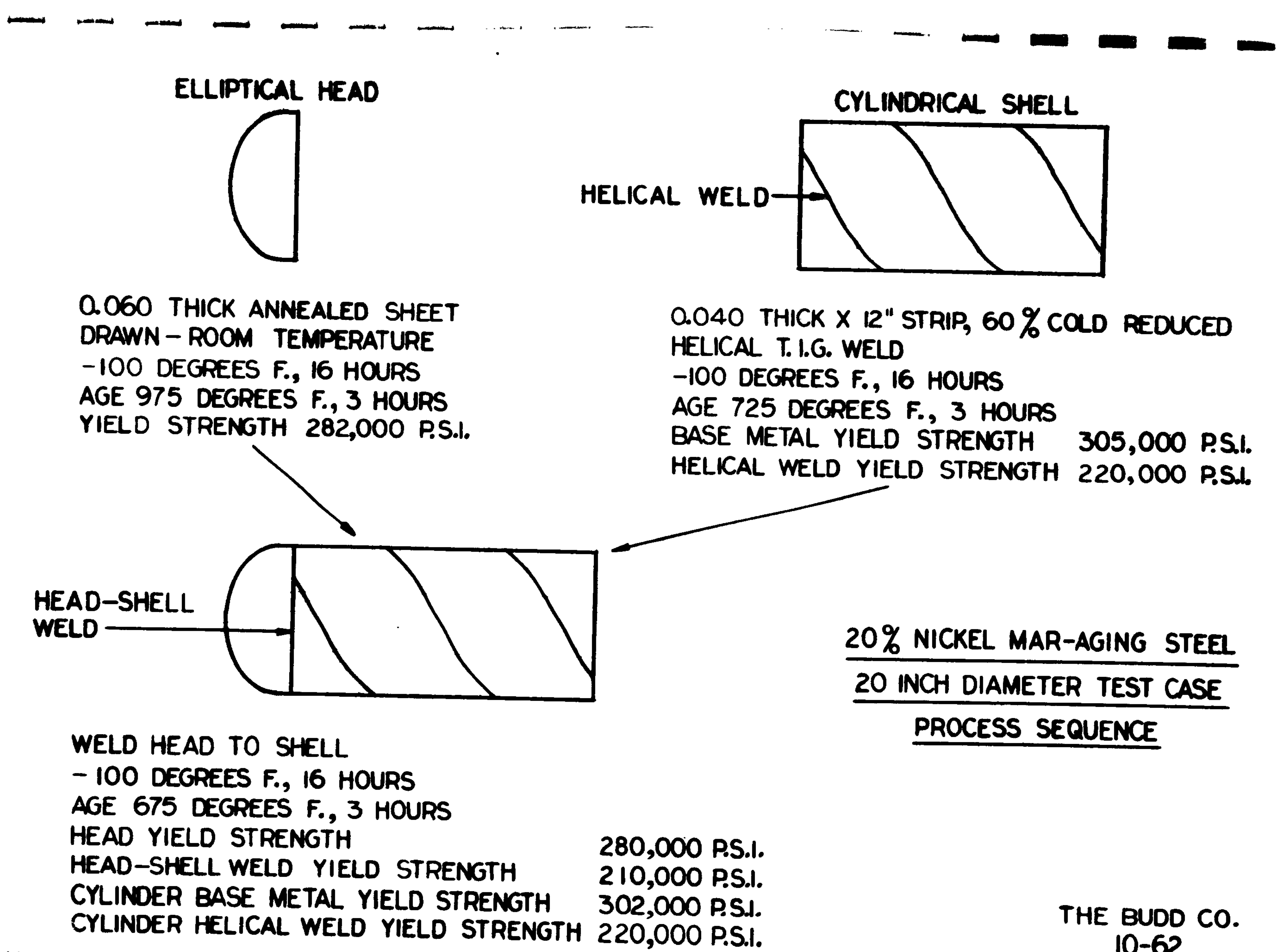

ELLIPTICAL HEAD
CYLINDRICAL SHELL
HELICAL WELD
0.060 THICK ANNEALED SHEET
DRAWN - ROOM TEMPERATURE
-100 DEGREES F., 16 HOURS
AGE 975 DEGREES F., 3 HOURS
YIELD STRENGTH 282,000 P.S.I.
0.040 THICK X 12" STRIP, 60 % COLD REDUCED
HELICAL T.I.G. WELD
-100 DEGREES F., 16 HOURS
AGE 725 DEGREES F., 3 HOURS
BASE METAL YIELD STRENGTH 305,000 P.S.I.
HELICAL WELD YIELD STRENGTH 220,000 P.S.I.
HEAD-SHELL WELD
WELD HEAD TO SHELL
- 100 DEGREES F., 16 HOURS
AGE 675 DEGREES F., 3 HOURS
HEAD YIELD STRENGTH 280,000 P.S.I.
HEAD-SHELL WELD YIELD STRENGTH 210,000 P.S.I.
CYLINDER BASE METAL YIELD STRENGTH 302,000 P.S.I.
CYLINDER HELICAL WELD YIELD STRENGTH 220,000 P.S.I.
20% NICKEL MAR-AGING STEEL
20 INCH DIAMETER TEST CASE
PROCESS SEQUENCE
THE BUDD CO.
10-62

Figure 28

Two cases were fabricated using this procedure.

Evaluation of Heat Treating Control Specimens

A system of control tensile specimen evaluation was established in conjunction with the manufacture of the 20 inch diameter test cases to verify, as nearly as possible, the actual mechanical properties of the case base metal and welds. Tensile specimens, having the same metallurgical and process histories, were attached to the case components and final assembly. These were subjected to the same thermal treatment as the case. The control specimens were tested and comparison made with design requirements and prior data obtained during materials evaluation before releasing the parts for the next process operation.

The results of the control specimen tests are described in the following portion of the report.

Base Metal Control Specimens - Head

As discussed in the materials evaluation section, the heat treatment of annealed and aged 0.065 inch head stock was to consist of annealing at 1500°F, followed by subzero cooling at -100°F for 16 hours, and aging for three hours at 1025°F.

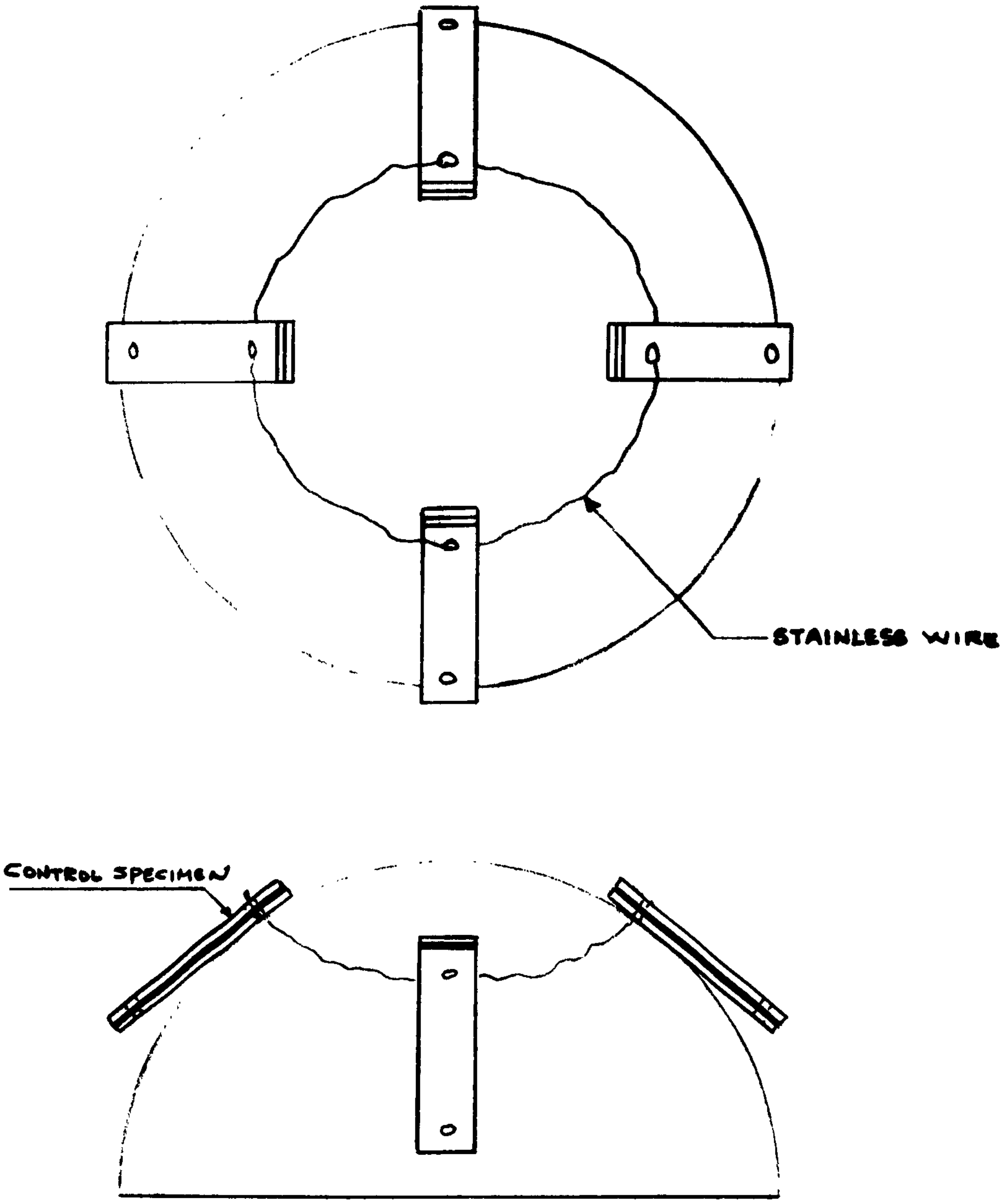
Two heads were placed in the furnace at one time in the commercial heat treatment. The furnace, used for

annealing at $1500^{\circ}F$, was a controlled atmosphere muffler type in which an argon atmosphere was used. The heads were placed in the furnace with the flanged edges resting on flat cast iron rings. The pieces were introduced into the furnace at a temperature lower than $500^{\circ}F$. Cooling was done in a separate chamber which was maintained at approximately $150^{\circ}F$, and which was also flooded with argon gas. Heavy scaling did not occur, but the surface was considerably discolored and darkened.

The aging treatment of the first two heads was carried out in a pit-type recirculating air furnace. The heads were stacked or nested in a fixture which separated them vertically by approximately five inches.

In both the annealing and aging treatments, the heads were accompanied by control specimens positioned on the work pieces, as illustrated by Figure 29.

In the pit-type furnace used for aging, the recirculating hot air entered through an opening in the center of the furnace bottom. The thermocouple controlling the furnace was located near the top of the chamber. The two heads stacked in the center of the lower part of the furnace apparently prevented adequate circulation. Consequently, the temperature reached a value higher than the $1025^{\circ}F$ set on the controller. Subsequent tests indicate that the temperature may have been as high as $1060^{\circ}F$.



TYPICAL CONTROL SPECIMEN LAYOUT
FOR HEAT TREATMENT OF HEADS.

Figure 29

THE BUDD Co
12/62

The pieces were placed in the furnace at a temperature less than 300°F to minimize distortion. The slow heating of the furnace and work essentially created a condition whereby the expected three hour aging time was greatly extended.

The results of the testing of the control specimens from the first two heads (NH-1 and NH-2) are shown in Table 46. These values are far below the 280,000 to 290,000 psi yield strength required in the design. A discussion with an International Nickel Company representative indicated that aging at such a high temperature could produce a small amount of relatively stable austenite which may not be readily dissolved upon reannealing at 1500°F. Laboratory reannealing, recooling and re-aging at 1025°F of the balance of the specimens showed that the hardness could not be increased. Heads NH-1 and NH-2 were abandoned and work was begun with the NH-3 and NH-4 heads.

The second two heads were aged in a pit-type recirculating air furnace in which the hot air entered around the periphery of the bottom. In addition, a thermocouple was placed directly on the work pieces to guarantee compliance with the specified 1025°F temperature. The pieces were put in a cold furnace, and therefore the time at temperature was a composite of heating and holding time. Table 47 shows the tensile data from these control specimens. The hardness and yield strength is greatly improved but falls well below the required level.

TENSILE PROPERTIES OF 20% NICKEL STEEL
Base Metal Control Specimens, Heads NH-1 and NH-2

0.065 Inch Gage Sheet
Cold Drawn, Annealed and Aged as Shown

Commercial Heat Treated
Heat No. 24022

Spec. No.	Heat Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation in 2 Inches	RC Hardness
NH1-1	-100°F, 16 hrs.	198	224	10	44-46
-3	1025°F, 3 hrs. *	202	232	11	
-5		216	240	10	
-7		222	238	10	
NH2-1	-100°F, 16 hrs.	197	242	10	44-46
-3	1025°F, 3 hrs. *	230	241	85	
-5		206	230	11	
-7		226	244	10	

* The specified temperature of 1025°F was surpassed because of heat treating difficulties. Temperature may have been as high as 1060°F. Time also was extended because of slow heating in a cold-charged furnace.

TABLE 46

TENSILE PROPERTIES OF 20% NICKEL STEEL
Base Metal Control Specimens, Heads NH-3 and NH-4

0.065 Inch Gage Sheet
Cold Drawn, Annealed and Aged as Shown

Commercial Heat Treated
Heat No. 24022

Spec. No.	Heat Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation in 2 Inches	RC Hardness
NH3-1	-100°F, 16 hrs. 1025°F, 3 hrs.	243	256	7	53.0
-2	Same	247	258	5	53.5
NH4-1	Same	254	266	4	54.0
-2	Same	254	265	6	54.5

TABLE 47

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7-26-62

Reannealing at 1500°F, cooling at -100°F and re-aging at 975°F allowed for development of sufficient tensile strength. The aging of the heads at 975°F was done one at a time in a small Budd Company recirculating air furnace. The data from the reannealing and aging of heads NH-3 and NH-4 are shown in Table 48. There is an apparent loss in properties after annealing, especially when the annealing is preceded by a slight over-age. Work done previously (See table 15) shows that aging at 975°F would produce yield strengths in the range of 298,000 psi to 302,000 psi.

Base Metal Control Specimens - Cylindrical Section

The aging temperature established for the 65% cold rolled case base metal was 725°F. After the welding of the head to the case, the assembly was sub-zero cooled and aged at 675°F for an additional three hours. The design yield strength of the case base metal was 300,000 psi to 310,000 psi. Eight tensile specimens were heat treated along with each fabricated case, through both aging treatments. All of the base metal and welded tensile specimens used as control specimens for the aging of both assemblies, NA-1 and NA-2, were taken from a production run-off section or extension from one end of the first case, NS-1. These were considered representative because of the apparent uniformity of the coil stock and because both cases were welded under identical conditions. The specimens were arranged around the case as shown on the diagram from the

TENSILE PROPERTIES OF 20% NICKEL STEEL
Base Metal Control Specimens, Heads NH-3 and NH-4

0.065 Inch Gage Sheet
Cold Drawn, Annealed and Subsequently Commercially Heat Treated as Shown

Heat No. 24022

Spec. No.	Heat Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation in 2 Inches	RD Hardness
NH3-3	-100°F, 16 hrs. 1025°F, 3 hrs. 1500°F, 40 mins. -100°F, 16 hrs. 975°F, 3 hrs.	280	288	3	55
-4		286	293	2	-
-5		277	284	2	-
-6		284	292	1	-
-7		286	293	1.5	55
NH4-3	Same	284	292	2.5	54
-4		284	293	3	-
-5		270	281	3.5	54.5
-6		287	296	2	54

TABLE 48

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heat treating specification, Figure 30.

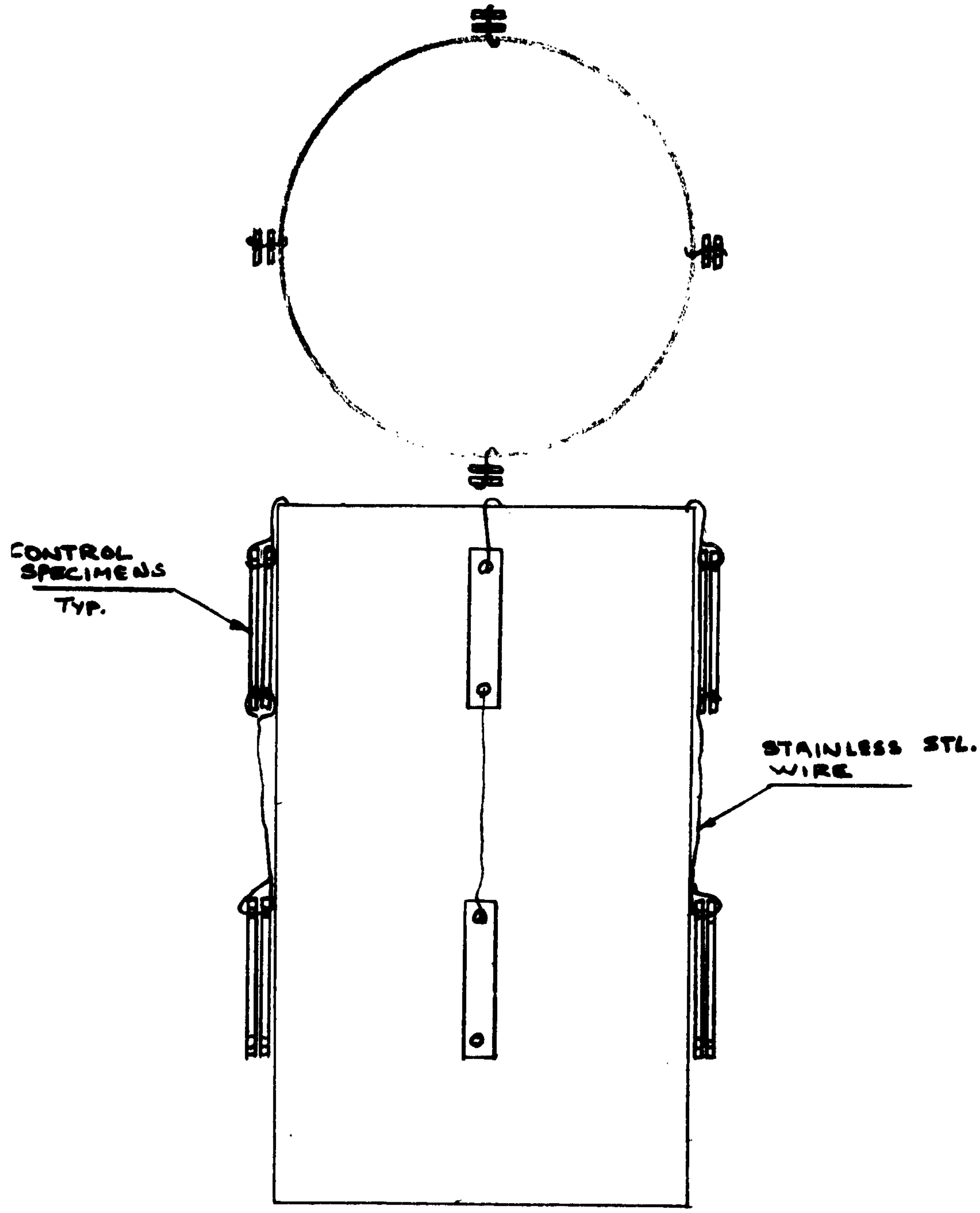
Aging was done in a pit-type recirculating air furnace. Although pieces were put in a cold furnace, no over-aging was experienced because of heating time. The aging temperature was rapidly reached and the intermediate temperatures were not sufficiently high to add to the aging response.

The tensile data from assemblies NA-1 and NA-2 are shown in Tables 49 and 50, respectively. The specimens from Assembly NA-1, which were single aged at 725°F, developed the same strength as those which were double aged. The specimens from Assembly NA-2 were equally satisfactory and generally met the design requirement. Minor differences in tensile values were undoubtedly caused by slight differences in the furnace.

<u>Head to Shell Weld Control Specimens</u>

In the welding of the heads to the cases, the materials joined were in different conditions. The heads had been annealed, sub-zero cooled, and aged at 975°F. The cases were made of cold rolled stock which was sub-zero cooled, and aged at 725°F. The joint in the "as welded" condition was of lower strength than acceptable for a girth weld. A sub-zero cool and age at 675°F was found to be required to develop the design strength of 190,000 to 210,000 psi.

It was impractical for control specimens to be made on



CONTROL SPECIMEN LAYOUT FOR 20 INCH DIA.
HELICAL WELDED CYLINDER

Figure 30

THE BOEING CO
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TENSILE PROPERTIES OF 20% NICKEL STEEL
Base Metal Control Specimens for Assembly NA-1

0.040 Inch Gage
Cold Rolled 60%

Commercially Heat Treated as Shown
Heat No. 24022

Spec. No.	Heat Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation in 2 Inches	RC Hardness
NS1-1	-100°F, 16 hrs. 725°F, 3 hrs.	310	310	1.5	-
-7		311	311	2.0	-
NS1-2	-100°F, 16 hrs. 725°F, 3 hrs.	*	304	1.5	53
-3	-100°F, 16 hrs. 675°F, 3 hrs.	*	308	1.5	53
-4		*	303	1.5	53
-5		*	312	-	54
-6		*	317	-	54
-8		*	306	1.5	54

*Failure occurred before reaching 0.2% offset.

TABLE 49

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TENSILE PROPERTIES OF 20% NICKEL STEEL
Base Metal Control Specimens for Assembly NA-2 *

0.040 Inch Gage
Cold Rolled 60%

Commercially Heat Treated as Shown
Heat No. 24022

Spec. No.	Heat Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation in 2 Inches	RC Hardness
NS2-1	-100°F, 16 hrs. 725°F, 3 hrs. -100°F, 16 hrs. 675°F, 3 hrs.	296	296	1.5	-
-2		302	302	1.5	52.5
-7		300	300	2.0	53
-8		317	317	1.5	54

* Balance of specimens used for reannealing and aging tests.

TABLE 50

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the head to shell welding fixture. Therefore, the control specimens for this joint were made by the laboratory welders using the same welding schedule and techniques.

The heads had a nominal metal thickness of 0.065 inch. This thickness was gradually reduced to about 0.040 inch along the three inch long cylindrical extension of the head. The 0.040 inch head was welded to the 0.040 inch case. The laboratory-made control specimens were not tapered on the 0.065 inch side, but were stepped from 0.065 inch to 0.040 inch about 1/2 inch from the weld.

Four specimens representing this joint accompanied each assembly through the sub-zero cool and 675°F aging treatment. They were hung on the assemblies in the region of the girth welds.

The results of the testing of two of these specimens from each case are shown in Table 51. The properties are slightly higher than expected, but show very satisfactory ductility.

In a later examination of the weld strength of the MA-1 assembly, three tensile specimens were taken from widely separated areas of the actual production made head to shell weld. With the material in the hardened condition, it was necessary to burn out the specimen blanks several inches over-size. The specimens were then shaped to the required blank size and the pin holes drilled. The rough contouring

TENSILE PROPERTIES OF 20% NICKEL STEEL
Head-to-Shell Weld Control Specimens for Assemblies NA-1 and NA-2

Before Welding: Head material annealed, sub-zero cooled, and aged 975°F, 3 hrs.
Case material cold rolled, sub-zero cooled, and aged 725°F, 3 hrs.

Spec. No.	Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation 1/2"	1"	2"
NA1-1	"as welded" plus -100°F, 16 hrs. 675°F, 3 hrs.	210	210	4	2	1
-2		214	216	3	2	1
NA2-1	Same	214	215	5	3	1
-2		208	210	6	3.5	1

TABLE 51

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of the reduced section was done using the electrical discharge machining process. The edges were finish ground before testing.

The welded joints of these specimens had received the single sub-zero cool and 675°F aging treatment. Table 52 shows the tensile data.

These values are lower than the laboratory - made head to shell control specimens discussed immediately above. However, the ductility is satisfactory and the fracture is normal in appearance. The values representing three points around the periphery of the joint are very uniform. The strengths obtained are adequate to meet design requirements for this joint.

Control Specimens - Helical Weld

As stated in a previous section, all of the base metal and welded control specimens for the aging of the two assemblies, NA-1 and NA-2, were taken from a production run-off section or extension from one end of the first case, NS-1. The welded specimens were wired to the case in a manner similar to the base metal specimens (see Figure 30 for a typical specimen location diagram).

After the full double aging treatment of the two fabricated chambers, the control specimens were tested. As discussed above, the base metal specimens from the case and from the head, and the specimens representing the head to

TENSILE PROPERTIES OF 20% NICKEL STEEL
Head-to-Shell Weld Specimens from Assembly NA-1

Before Welding: Head material annealed, sub-zero cooled, and aged 975°F, 3 hrs.
Case material cold rolled, sub-zero cooled, and aged 725°F, 3 hrs.

Spec. No.	Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation 1/2"	1"	2"
NAT-1	"as welded" plus -100°F, 16 hrs. 675°F, 3 hrs.	196	197	5	-	-
NAT-2	Same	196	198	5	-	-
NAT-3	Same	192	195	5	-	-

TABLE 52

The Budd Co.
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shell weld tested to the required strength levels. However, the production made helical weld specimens, which had been similarly heat treated, did not achieve the expected properties. Table 53 shows the test values of some of the welded specimens from Assembly NA-1.

The ultimate strength values were exceptionally low and the elongation values were not proportionately higher. In most cases failure occurred without the specimen reaching the 0.2% offset yield strength. A single specimen, NS-1-XW, which had received only the first sub-zero cool and age (725°F), was equally poor.

After these findings, an immediate effort was made to establish the reasons for such an unsatisfactory performance. Additional specimens were taken from an "as welded" case that was welded chronologically between the NS-1 and NS-2 cases. This part had been scrapped because of a weld burn through, caused by mechanical failure of the material feeder in the welding fixture. The remaining sections of the helical weld were made under identical conditions as the welds in cases NS-1 and NS-2. For discussion purposes, this case will be referred to as NS-3.

Case NS-3 was sectioned, and welded tensile specimens were tested after various treatments. A compilation of this series of tests is shown in Table 54.

TENSILE PROPERTIES OF 20% NICKEL STEEL
TIG Welded Control Specimens for Assembly NA-1

0.040 Inch Gage
Base Metal Cold Rolled 60%

Commercially Heat Treated as Shown
Heat No. 24022

Spec. No.	Heat Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation 1/2"	1"	2"	RC Hardness
NS1-1W	-100°F, 16 hrs. 725°F, 3 hrs.	-	66	2	1.5	1	54
NS1-2W	-100°F, 16 hrs. 675°F, 3 hrs.	-	86	2	1.5	1	53
NS1-3W	Same	-	88	2	1.5	1	53
NS1-7W	Same	-	88	2	1.5	1	55
NS1-XW	-100°F, 16 hrs. 725°F, 3 hrs.	109	109	2	2	2	-

TABLE 53

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TENSILE PROPERTIES OF 20% NICKEL STEEL

Case NS-3

Production TIG Welded
0.040 Inch Gage, Col Rolled 60%

Heat Treated as Shown
Heat No. 24022

Spec. No.	Condition	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation 1/2"	1"	2"	Location of Failure
NT-1	"As welded", plus $-100^{\circ}F$, 16 hrs.	149	160	8	4	2	HAZ
-5		159	162	8	5	3	"
-11		161	165	8	4	3	
NT-9	"As welded", plus $725^{\circ}F$, 3 hrs. (no $-100^{\circ}F$)	-	179	3	1.5	1.0	HAZ
-10		-	156	3	1.5	1.0	"
-15		-	167	3	1.5	1.0	"
NT-3	"As welded", plus $-100^{\circ}F$, 16 hrs. $725^{\circ}F$, 3 hrs. $-100^{\circ}F$, 16 hrs. $675^{\circ}F$, 3 hrs.	-	96	2	1.0	0.5	HAZ
-4		-	52	4	2.0	1.0	"
-7		-	66	2	1.0	0.5	"
-13		-	135	4	2.0	1.0	"
NT-2	"As welded", plus $-100^{\circ}F$, 16 hrs. $725^{\circ}F$, 3 hrs.	112	113	3	1.5	1.0	HAZ
-6		189	190	3	1.5	1.0	"
-12		192	193	4	2.0	1.0	"
-16		-	111	4	2.5	1.5	"
-20		-	159	2	1.5	1.0	"
-22		-	126	2	2.0	1.0	"
-24		-	114	3	2.0	1.0	"
-26		-	99	2	1.5	1.0	"
NT-17	"As welded", plus $-100^{\circ}F$, 16 hrs. Immersion in 2% NaCl Solution 1 hr. $725^{\circ}F$, 3 hrs. Immersion in 2% NaCl Solution 1 hr.	-	162	4	3	1.0	HAZ
-19		-	157	4	2.5	1.0	"
-21		-	139	3	2	1.0	"

TABLE 54

The Budd Co.
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The "as welded" specimens appeared to have normal properties, although the strengths were 10% lower than had been achieved with laboratory test samples. Aging, whether single aged at 725°F or double aged at 725°F and 675°F, created a condition which caused extremely erratic and generally very poor properties. In most cases the 0.2% offset yield strength was not reached, and failure always occurred in the heat affected zone (HAZ) in the region of the bead-to-base-metal interface.

The possible effect of stress corrosion, which could be caused by chloride ions, was superficially evaluated by immersion of three test pieces in a 2% NaCl solution before and after aging. No difference was noted in the tensile properties, as compared to the balance of the specimens. Aged specimen strengths were scattered throughout the range from 66,000 psi to 193,000 psi tensile strength. No specimen reached the expected value of about 210,000 psi.

With the unfavorable results of both the control specimens and the specimens from Case NS-3, it was decided to sacrifice the first assembly NA-1 for test purposes. A random sampling of welded tensile specimens were taken from each end and the middle of the helical weld. The test results from these specimens are shown in Table 55.

The test data show that the same condition existed in the assembled part, at least in the helical weld. The head

TENSILE PROPERTIES OF 20% NICKEL STEEL

Production TIG welded (taken from Assembly NA-1 *)
Base Metal: 0.040 Inch Gage, Cold Rolled 60%

Commercially Heat Treated as Shown
Heat No. 24022

Spec. No.	Heat Treatment After Welding	Yield Strength ** 0.2% Offset KSI	Ultimate Strength KSI	% Elongation 1/2"	1"	2"	RC Hardness
NST-1	$-100^\circ F$, 16 hrs. $725^\circ F$, 3 hrs.	-	-	-	-	-	-
-2	$-100^\circ F$, 16 hrs. $675^\circ F$, 3 hrs.	-	125	3	2	1	53.5
-3		-	169	3	2	1	53.5
-4		-	-	-	-	-	-
-5		-	110	3	2	1	53.5
-6		-	106	2	2	1	53
-X1		-	151	3	2	1	53.5
-X2		-	176	4	2	1	53
-X3		-	146	4	3	1	53

* Random sampling of helical weld from each end and middle.

** Failure occurred before reaching 0.2% offset.

TABLE 55

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to shell weld proved to be of better quality and the tensile strength, although slightly lower than expected, was ample to meet design requirements. The head to shell weld test data are shown in Table 52 and were discussed in a preceding section.

A later section of this report will describe the action taken to determine the cause of the adverse weld response.

Reannealing and Aging of Case No. NA-2

Laboratory Heat Treatment of T.I.G. Welded and Base Metal Specimens

The test results of the helical weld control specimens and subsequent tests of specimens removed from assembly NA-1 left little doubt that the second assembly also had a low strength helical weld and therefore hydrotest was inadvisable. It was decided to re-solution anneal and re-age case No. NA-2 as a possible means of improving weld strength and thereby salvaging the test case.

There were essentially four different material conditions present in the assembly:

1. Head base metal, annealed and aged.
2. Case base metal, cold rolled and aged.
3. Head to shell weld, single aged, test satisfactory.
4. Helical weld, double aged, test not satisfactory.

The response to heat treatment would be expected to be different for each condition. Specimens representing each condition, and having had the same thermal history as the elements, were simultaneously re-solution annealed at 1500°F for 20 minutes at temperature. Annealing was done in a folded sheet metal retort, in which an argon atmosphere was maintained. The slower heating of commercial equipment was assimilated by placing the work in a furnace at 500°F and heating to the 1500°F annealing temperature at about 400°F per hour. At the end of the cycle, the retort was air cooled.

Previous experience with these steels indicated that the best compromise of strength in all parts of the assembly would be achieved by aging in the range of 925°F to 975°F. The tensile properties of the laboratory reannealed specimens of welds and base metal aged at 925°F and 975°F are shown in Tables 56 and 57. These tensile strengths are plotted versus aging temperatures in Figure 31.

The case base metal properties were used to establish the final aging temperature. The 925°F temperature produced values close to the 300,000 psi minimum yield strength originally required. The 975°F aging produced yield strength values only slightly lower.

The properties of the reannealed and aged head specimens were more favorable at the lower aging temperature.

TENSILE PROPERTIES OF 20% NICKEL STEEL
TIG Welded Specimens *

Laboratory annealed at 1500°F, 30 min. in argon, cooled at -100°F, 16 hours, and aged at indicated temperatures for 2½ hours.

Spec. No.	Area Represented	Aging Temp. Degrees Fahrenheit	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation in 1/2 Inch
NS2-2W	Helical Weld	925	-	263	3
NS2-4W	" "	925	-	238	3
NS2-3W	" "	975	-	282	3
NS2-5W	" "	975	-	255	3
NS2-8W	" "	975	-	280	3
NA1-3	Head-to-Shell Weld	925	317	321	4
NA1-4	" " " "	975	308	312	3

*See Figure 28 for processing history of specimens

TABLE 56

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TENSILE PROPERTIES OF 20% NICKEL STEEL
Base Metal Specimens *

Laboratory annealed at 1500°F, 30 min. in Argon; cooled at -100°F, 16 hours; and aged at indicated temperatures for 2½ hours.

Spec. No.	Area Represented	Aging Temp. Degrees Fahrenheit	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation in 2 Inches
NS2-3	Case	925	298	308	2.5
NS2-5	"	925	302	309	2.5
NS2-4	"	975	292	300	2.5
NS2-6	"	975	299	299	2.5
N1	Head	925	288	297	2.5
N5	"	925	279	290	-
N7	"	925	276	286	2.0
N2	"	975	280	288	3.0
N4	"	975	288	298	3.5
N6	"	975	295	305	3.0
N8	"	975	274	283	2.0

* See Figure 28 for processing history of specimens.

TABLE 57

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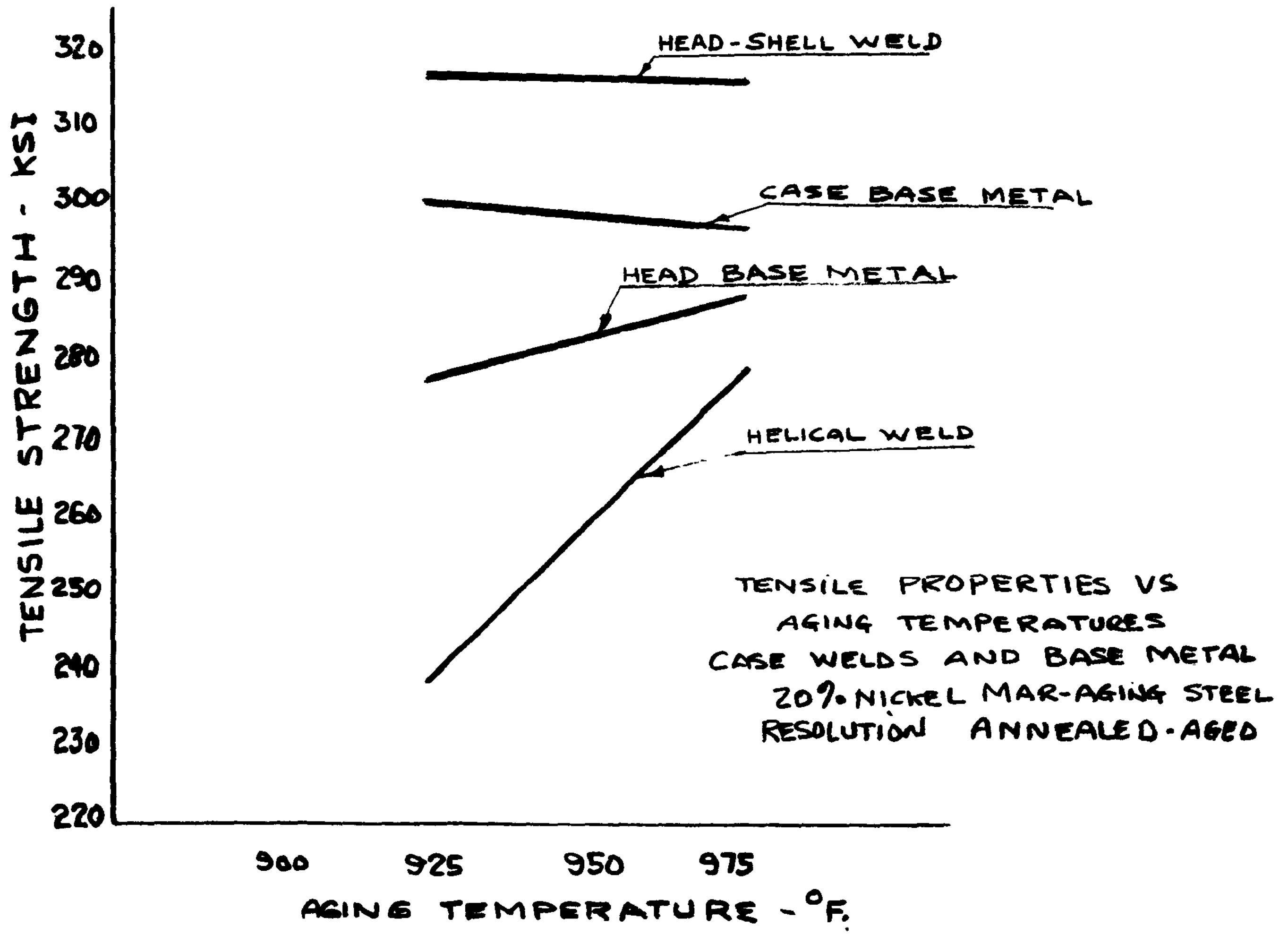
HEAD-SHELL WELD
CASE BASE METAL
HEAD BASE METAL
HELICAL WELD
TENSILE PROPERTIES VS
AGING TEMPERATURES
CASE WELDS AND BASE METAL
20% NICKEL MAR-AGING STEEL
RESOLUTION ANNEALED-AGED
TENSILE STRENGTH - KSI
320
310
300
290
280
270
260
250
240
230
220
900
925
950
975
AGING TEMPERATURE - °F.

Figure 31

The helical weld specimens improved considerably from the original "as welded", sub-zero cooled, and 725°F aged properties. However, the strengths were below what might be expected, and the results were abnormally scattered. All of the strengths were above the design value required for the helical joint.

Only one head to shell specimen was available for each aging temperature. Both of these responded with very high strength values. The strengths are superior to the base metal properties, although both annealing and aging of all specimens were done simultaneously.

From the data obtained, an aging temperature of 940°F was selected for the commercial reanneal and aging of the case.

Heat Treatment of Assembly NA-2, and T.I.G. Welded and Base Metal Control Specimens

Control specimens representing all conditions of assembly NA-2 were wired to the chamber in a manner similar to that used for the original aging of the piece. It was necessary to heat treat some of the test coupons prior to use as control specimens to establish the same thermal history as the areas of the assembly that they were to represent. Tables 58 and 59 show a compilation of the background of all the specimens used for the laboratory study, and the actual commercial heat treatment of the NA-2 assembly.

PROCESSING HISTORY OF BASE METAL CONTROL SPECIMENS
FOR REANNEALING AND AGING OF ASSEMBLY NA-2

Spec. Nos.	Source	Initial Condition	Initial Heat Treatment	Where Treated	Second Heat Treatment	Where Treated
NS2-3 and NS2-5	Runoff of Shop Welded Case NS1	Cold Rolled	-100°F, 16 hrs. 725°F, 3 hrs. -100°F, 16 hrs. 675°F, 3 hrs.	Lab.	1500°F, 30 min. 925°F, 2½ hrs.	Lab.
NS2-4 and NS2-6	Same	Same	Same	Lab.	1500°F, 30 min. 975°F, 2½ hrs.	Lab.
N1, N5 and N8	Head Blank Scrap	1500°F, 30 min. -100°F, 16 hrs. 1000°F, 3 hrs. 1500°F, 30 min. -100°F, 16 hrs. 975°F, 3 hrs.	-100°F, 16 hrs. 675°F, 3 hrs.	Lab.	1500°F, 30 min. 925°F, 2½ hrs.	Lab.
N2, N4, N6 and N8	Same	Same	Same	Lab.	1500°F, 30 min. 975°F, 2½ hrs.	Lab.
S2-1 through S2-8	Case NA-1	Cold Rolled	-100°F, 16 hrs. 725°F, 3 hrs. -100°F, 16 hrs. 675°F, 3 hrs.	Comm.*	1500°F, 30 min. 940°F, 2½ hrs.	Comm.*
NH3-8, NH4-7 and NH4-8	Head Blank Scrap	1500°F, 30 min. -100°F, 16 hrs. 1025°F, 3 hrs. 1500°F, 30 min. -100°F, 16 hrs. 975°F, 3 hrs.	-100°F, 16 hrs. 675°F, 3 hrs.	Comm.*	1500°F, 30 min. 940°F, 2½ hrs.	Comm.*

* Commercial

TABLE 58

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PROCESSING HISTORY OF WELDED CONTROL SPECIMENS
FOR REANNEALING AND AGING OF ASSEMBLY NA-2

Spec. No.	Source	Initial Condition	Initial Heat Treatment	Where Treated	Second Heat Treatment	Where Treated
NS2-2W, NS2-4W and NS2-6W	Runoff of Shop Welded Case NA-1	Cold Rolled	-100°F, 16 hrs. 725°F, 3 hrs. -100°F, 16 hrs. 675°F, 3 hrs.	Comm.*	1500°F, 30 min. -100°F, 16 hrs. 925°F, 2½ hrs.	Lab.
NS2-3W, NS2-5W and NS2-8W	Same	Same	Same	Comm.*	1500°F, 30 min. -100°F, 16 hrs. 975°F, 2½ hrs.	Lab.
NA1-3	Lab. Welded Specimen from Case NA-1	Annealed and Aged, Welded to Cold Rolled and Aged	-100°F, 16 hrs. 675°F, 3 hrs.	Comm.*	1500°F, 30 min. -100°F, 16 hrs. 925°F, 2½ hrs.	Lab.
NA1-4	Same	Same	Same	Comm.*	1500°F, 30 min. -100°F, 16 hrs. 975°F, 2½ hrs.	Lab.
S2-1W through S2-5W	Shop Welded Case NA-1	Cold Rolled	-100°F, 16 hrs. 725°F, 3 hrs. -100°F, 16 hrs. 675°F, 3 hrs.	Lab.	1500°F, 30 min. -100°F, 16 hrs. 940°F, 2½ hrs.	Comm.*
NS1-4 through NS1-8	Same	Same	Same	Same	Same	Same
NA2-3, NA2-4	Lab. Welded Specimens from Case NA-2	Same as NA1-3 above.	-100°F, 16 hrs. 675°F, 3 hrs.	Comm.*	1500°F, 30 min. -100°F, 16 hrs. 940°F, 3½ hrs.	Comm.*

* Commercial.

TABLE 59

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The annealing of the assembly was done at 1500°F for 30 minutes. The piece was sealed in a retort three feet in diameter by about six feet high. The retort was thoroughly purged with argon and placed into the furnace in a vertical position. Upon return of the furnace to the 1500°F temperature, an additional 30 to 40 minutes was allowed. The retort was removed from the furnace and water-spray cooled to about 200°F in approximately 15 minutes. The argon atmosphere was maintained throughout the entire procedure.

An air atmosphere was used for the aging of the assembly at 940°F for two and one-half hours. The same specimens accompanied the chamber through this process. As preceding all aging treatments, the assembly was sub-zero cooled at -100°F for 16 hours.

The results of the testing of the welded and base metal control specimens are shown in Tables 60 and 61.

The head and case base metal properties are as expected, and fall precisely in the range required.

The head to shell weld specimens were also satisfactory, with one value slightly lower than the other, and showing lower ductility.

The general range of values of the helical welds was approximately the same as the range experienced with the laboratory annealing and aging study. However, one tensile

TENSILE PROPERTIES OF 20% NICKEL STEEL
0.065 Inch Gage Sheet
TIG Welded Control Specimens for Assembly MA-2 *

Commercially annealed at 1500°F, 30 min. in argon; cooled at -100°F, 16 hours; and aged at 940°F, 2½ hours.

Spec. No.	Area Represented	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation in 1/2 Inch
S2-1W	Helical Weld	-	214	2
-2W	" "	-	244	3
-3W	" "	-	292 **	3
-4W	" "	-	110 **	2
-5W	" "	-	277	6
MS1-4W	Helical Weld	-	246	2
-5W	" "	-	227	-
-6W	" "	-	268	-
-8W	" "	-	228	2
MA2-3	Head-to-Shell Weld	-	298	2
-4	" " " "	-	313	3

* See Figure 28 for processing history of specimens.

** Photomicrographs made of these weld cross-sections.

TABLE 60

The Budd Co.
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TENSILE PROPERTIES OF 20% NICKEL STEEL
0.065 Inch Gage Sheet
Base Metal Control Specimens for Assembly MA-2 *

Commercially annealed at 1500°F, 30 min. in Argon; cooled at -100°F, 16 hours; and aged at 940°F, 2½ hours.

Spec. No.	Area Represented	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation in 2 Inches
S2-1	Case	300	308	2
-2	"	300	309	-
-3	"	291	300	2.5
-4	"	302	310	2
-5	"	299	306	2
-6	"	299	309	-
-7	"	294	302	2
-8	"	300	302	2
MH3-8	Head	270	282	3
MH4-7	Head	285	294	2.5
MH4-8	Head	282	290	2

* See Figure 28 for processing history of specimens.

TABLE 61

The Budd Co.
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strength value was slightly low at 214,000 psi and another and another extremely low at 110,000 psi.

If the helical weld control specimens are truly representative of the weld in the case, and there is no reason to believe that they are not, then the success of the assembly in a burst test could not be assured. This assembly was set aside and the planned hydrostatic burst test was delayed pending the outcome of subsequent investigations of the apparent variation in the properties of the helical welds.

Heat Treating Compatibility of AM-350 With 20% Nickel Steel

The NA-2 assembly, which had been reannealed and aged, had extra skin sheets or doublers resistance welded to the outside of one end. The purpose of this was to effect a transition from the test area of the case to the rigid plug closure to be used at that end. The material used was cold rolled and aged (CRT) AM-350 stainless steel with a yield strength of approximately 200,000 psi. It was necessary to determine what the properties would be after exposure to the annealing and aging cycle required by the 20% nickel material. The data from the testing of four specimens of the AM-350 steel are shown in Table 62. The heat treatment, including the sub-zero cool, was reasonably compatible to produce average yield strength of 180,000 psi, with an elongation of 10%.

TENSILE PROPERTIES OF AM-350

Heat Treating Compatibility with 20% Nickel Steel
0.030 Inch Gage

Original Condition: CRT, with approximate yield strength of 200,000 psi.

Spec. No.	Heat Treatment *	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation in 2 Inches
350-1	1500°F, 30 min. -100°F, 16 hrs. 940°F, 2½ hrs.	183	200	12
-2		183	201	11
-3		178	197	7
-4		178	196	9

* This heat treatment required for the 20% nickel alloy.

TABLE 62

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Investigation Into Cause of Low Strength Helical Welds

Tensile tests of control specimens representing the cylinder helical weld of test cases NA-1 and NA-2 showed considerable scatter in yield strength values and in some instances, as shown in the previous data, the weld strength was below design requirements. Hydrotest of the two cases was therefore held up.

A program was initiated to determine the possible cause of the erratic and low strength response to aging obtained in the helical weld. The investigation was conducted in the following areas:

1. Case NA-1, the first case manufactured for hydrotest was sectioned and tensile specimens were cut from the helical weld and head to shell weld to confirm results obtained from control specimens.

2. A laboratory study was made to determine the effect of weld process variables on the aged weld strength. This included wire cleanliness, chill variations, width and depth of gas groove, weld schedule, photomicrographic comparisons of good and low strength welds, aging temperature and time variations.

3. The International Nickel Company's Bayonne Research Laboratory conducted a chemical analysis of composition of base metal, weld deposit and weld wire

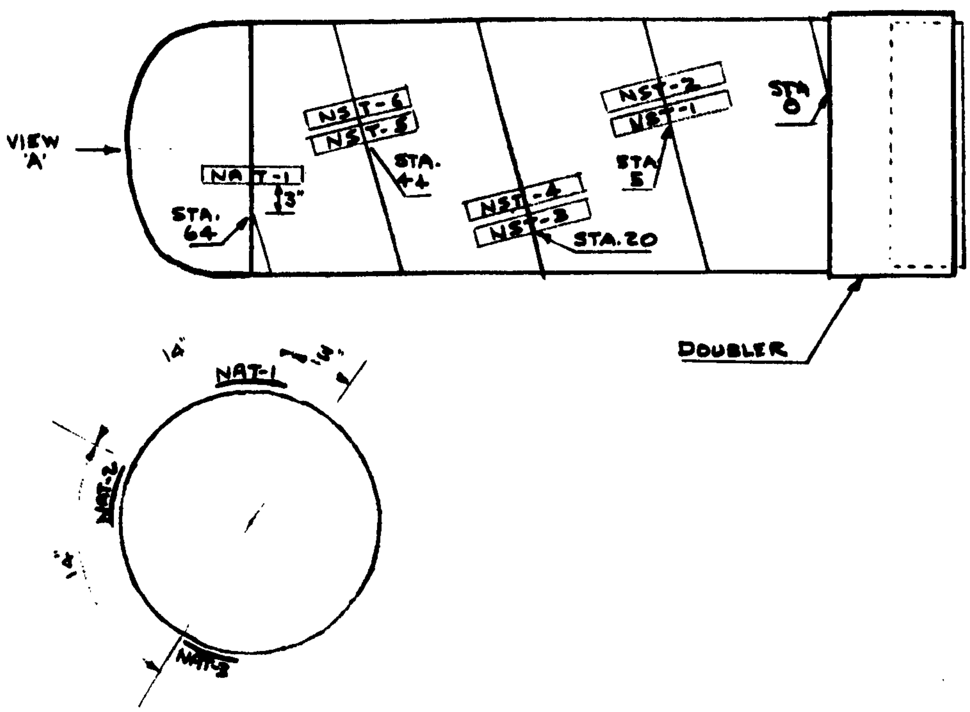
to determine if these elements were contributing to the strength degradation. In addition, INCO determined the gas content in weld wire, base metal and weld deposit was a possible cause for low strength welds.

The first 20 inch diameter test case was sectioned and tensile specimens were removed to confirm the results of tensile tests of control specimens, which were attached to the case during heat treatment. Figure 32 shows the location on the case of specimens removal.

Table 63 is a summary of tensile tests of specimens taken from case NA-2. Standard tensile specimens were used and rough machining was done by the electrical discharge method. Gage lengths were ground to final dimension. The three head to shell welds averaged 194,000 psi tensile strength and showed adequate ductility. These were acceptable values. The helical weld specimens were low and ranged from 106,000 to 176,000 psi. Failures were brittle and occurred in the interface area between the heat affected zone and weld nugget. This confirmed the results obtained from the control specimens. These results indicated the need for additional investigation into causes of low strength in aged welds.

A 20 inch cylindrical section was welded in the helical welding fixture under identical conditions used for the test cases NA-1 and NA-2. Due to a mechanical malfunction of the

20 INCH DIAMETER TEST CASE NO. NA-1
LOCATION OF SPECIMENS CUT FROM
CASE TO VERIFY CONTROL SPECIMEN DATA



VIEW 'A'

NOTE: STATIONS ARE LOCATED AT 3 INCH INTERVALS ALONG WELD LINE, STARTING AT STA 0 WHERE WELD INTERSECTS DOUBLER

Figure 32

TENSILE PROPERTIES - 20% NICKEL STEEL WELD JOINT
SPECIMENS TAKEN FROM 20 INCH CASE NA-1

.040 20% Nickel Steel
Heat No. 24022

Specimen No.	Description of Specimen	Tensile Strength KSI	Elongation % in 2 Inches
NAT-1	Head - Shell Girth Weld	197	4.5
	-100°F 16 hours	196	5.0
	725°F 3 hours	192	5.0
NST-1	Helical Weld	-	- *
-2	-100°F 16 hours	125	3.0
-3	725°F 3 hours	169	1.0
-4		-	- *
-5		110	-
-6		106	-
Control Specimens'	Helical Weld - Cylinder	66	-
		88	-
		100	-
Case NA-1	Base Metal - Cylinder	305	-
(For Comparison)	Base Metal - Head	290	-
	Weld - Head to Cylinder	205	-

* Specimen broke during manufacture.

TABLE 63

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drive, a burn-through occurred in the weld. This cylinder was not heat treated or subjected to any additional processing. A series of tensile specimens were taken from this cylinder and subjected to various heat treat combinations to determine the effect on weld strength characteristics. The various treatments and test results are shown in Table 64. In this series of tests the "as welded" specimens were satisfactory and strengths were reasonably consistant and at the level to be expected for the alloy. However, after sub-zero cool and aging at 720°F and 725°F, the strengths were low and variations occurred ranging from 112 ksi yield strength to 192 ksi. This was not consistant with values developed during the weld evaluation of the 20% nickel steel or in the preliminary verification of weld properties of heat No. 24022.

Since the properties of helical welds made in the machine did not match welds made in the laboratory, it was felt that the difference could be due to variation in welding methods and physical differences in the fixturing. Chill and gas backup effects were suspected. In the helical welding fixture the strip passes between fixed shoes, which holds the edges of the strip in position and serves as a means of supplying gas backup and to provide chill. Since the chill block remains in one position with respect to the welding head, the temperature of the chill block increases and its effectiveness as a chill is decreased.

TENSILE PROPERTIES OF 20% NICKEL STEEL
T.I.G. HELICAL WELD SPECIMENS TAKEN FROM HELICAL WELDED CYLINDER (NS-3)
HEAT TREATMENTS AS SHOWN

Base Metal .040 Gage
Cold Rolled 60%

Filler Wire Heat No. 7-C-088

Heat No. 24022

Specimen No.	Heat Treatment	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation Percent in ½"	1"	2"
NT-1	Weld	149	160	8	4	2
NT-5	-100°F, 16 hours	159	162	8	5	3
NT-11		161	165	7	4	3
NT-2	Weld	112	113	3	1.5	1
NT-6	-100°F, 16 hours	189	190	3	1.5	1
NT-12	Age 725°F, 3 hours	192	193	4	2	1
NT-3	Weld	-	96	2	1	0.5
NT-7	-100°F, 16 hours	-	66	2	1	0.5
NT-13	Age 725°F, 3 hours	-	135	4	2	1
	-100°F, 16 hours					
	Age 625°F, 3 hours					
NT-4	Weld	-	52	4	2	1
NT-8	-100°F, 16 hours	-	121	2	1	0.5
NT-14	Age 725°F, 4 hours	-	-			
	-100°F, 16 hours					
	Age 675°F, 4 hours					
NT-9	Weld	-	179	3	1.5	1
NT-10	No -100°F Treatment	-	156	3	1.5	1
NT-15	Age 725°F, 3 hours	-	167	3	1.5	1

TABLE 64 (Continued)

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TENSILE PROPERTIES OF 20% NICKEL STEEL
T.I.G. HELICAL WELD SPECIMENS TAKEN FROM HELICAL WELDED CYLINDER (NS-3)
HEAT TREATMENTS AS SHOWN

Specimen No.	Heat Treatment	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation Percent in ½"	1"	2"
NT-16	Weld	-	111	4	2.5	1.5
NT-18	-100°F, 16 hours	-	166	2	1.5	1
NT-20	Age 725°F, 3 hours	-	159	2	1.5	1
NT-22		-	126	2	2	1
NT-24		-	114	3	2	1
NT-26		-	99	2	1.5	1
NT-17	Weld	-	162	4	3	1
NT-19	-100°F, 16 hours	-	157	4	2.5	1
NT-21	Age 725°F, 3 hours Submerge in 2% N_aCl Solution ½ hour	-	139	3	2	1

TABLE 64 (Continued)

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An attempt was made to simulate the welding conditions, found in the helical weld fixture, in the weld laboratory by varying the position of the chill blocks and clamping bars. Figure 33 shows the fixture arrangement used in making this group of specimens. The results of tensile tests are summarized in Tables 65 and 66. Weld wire used was from heat No. 7-C-088, supplied by Allegheny-Ludlum, and had identical composition to the base metal. Hand cleaning of weld wire was done on some specimens and on others the wire was in the "as received" condition. Established welding schedules were used.

As shown in the data using a "normal" chill (same as previous laboratory welds), the weld tensile strengths were low and variations ranging from 77 ksi to 200 ksi were recorded. Surface cleaning the weld wire immediately prior to welding did not make a significant difference in tensile properties over wire in the "as received" condition (mill cleaned and spooled). Modifying the chill arrangement, as per Figure 33, resulted in similar tensile values. Due to the increased distance from the weld of the clamp and backup support, greater difficulty was encountered in controlling mismatch. Tensile properties attained in the weld evaluation program were not duplicated by the laboratory in this group of tests.

Various special conditions of base metal and welds were established to obtain data on strength response. Two specimens of base metal (.040 inch thick cold rolled 60%) were

WELDING FIXTURE ARRANGEMENT FOR MODIFYING
CHILL - HELICAL WELD SIMULATION

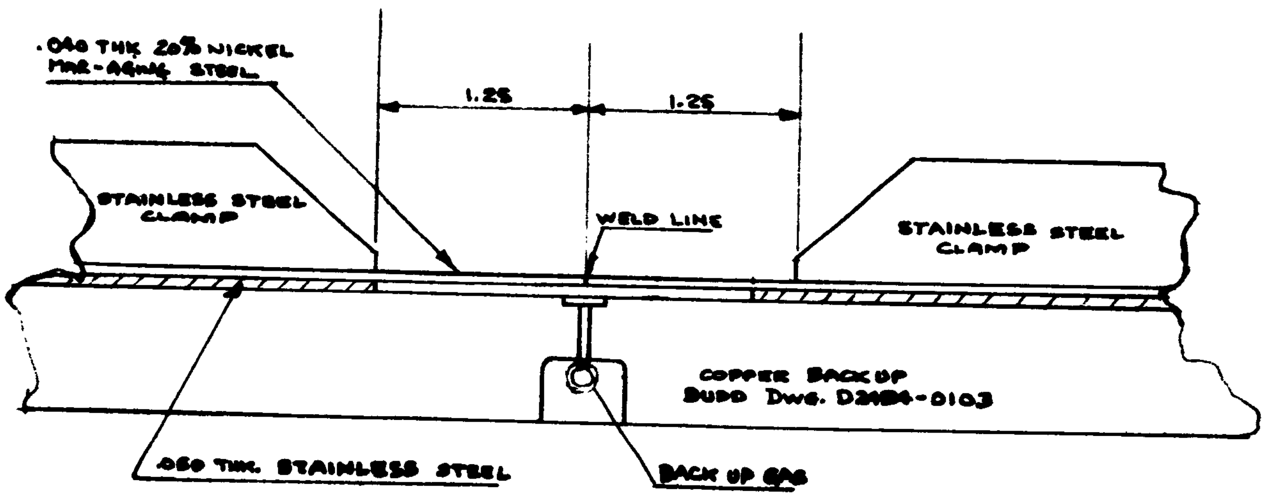

Figure 33

TENSILE PROPERTIES OF 20% NICKEL STEEL

LABORATORY T.I.G. WELDS - VARIOUS CONDITIONS OF WIRE CLEANLINESS AND CHILL RATES

Base Metal - Cold Rolled 60%
0.040 Inch Gage

Filler Wire Heat No. 7-C-088

Heat No. 24022
Aged as Shown

Specimen No.	Chill[1]	Wire Condition[2]	Aging[3] Temp. °F.	Aging[3] Time Hours	Ultimate Strength[4] KSI	Fracture Appearance[5] Ductile	Fracture Appearance[5] Brittle
HNCT-40	Normal	Clean	725	3	153	4/5	1/5
41	"	"	725	3	77	1/2	1/2
42	Normal	Clean	725 + 675	3	107	7/8	1/8
43	"	"	725 + 675	3	109	7/8	1/8
44	Normal	Clean	725 + 675	2	195	15/16	1/16
45	"	"	725 + 675	2	186	15/16	1/16
46	Normal	As Received	725	3	194	15/16	1/16
47	"	" "	725	3	187	15/16	1/16
48	Normal	As Received	725 + 675	3	190	15/16	1/16
49	"	" "	725 + 675	3	149	2/3	1/3
50	Normal	As Received	725 + 675	2	202	All	None
51	"	" "	725 + 675	2	141	7/8	1/8

1. Normal Chill similar to chill used in previous laboratory welding. Described in Figure
2. Wire "As Received" had slight "smut" on surface which had not been removed in production welding.
3. All aging treatments preceded by cooling at -100°F for 16 hours.
4. In most cases fracture occurred before reaching the 0.2% offset yield value.
5. Distribution of a brittle appearance on fracture surface of welds.

TABLE 65 (Continued)

The Budd Co.
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TENSILE PROPERTIES OF 20% NICKEL STEEL

LABORATORY T.I.G. WELDS - VARIOUS CONDITIONS OF WIRE CLEANLINESS AND CHILL RATES

Specimen No.	Chill[1]	Wire Condition[2]	Aging[3] Temp. °F	Aging[3] Time Hours	Ultimate Strength[4] KSI	Fracture Appearance[5] Ductile	Fracture Appearance[5] Brittle
HNCT-52	Moderate	Clean	725	3	171	7/8	1/8
53	"	"	725	3	153	3/4	1/4
54	Moderate	Clean	725 + 675	3	158	3/4	1/4
55	"	"	725 + 675	3	-	-	-
56	Moderate	Clean	725 + 675	2	202	All	None
57	"	"	725 + 675	2	179	15/16	1/16
58	Moderate	As Received	725	3	148	2/3	1/3
59	"	" "	725	3	105	15/16	1/16
60	Moderate	As Received	725 + 675	3	124	1/2	1/2
61	"	" "	725 + 675	3	115	1/2	1/2
62	Moderate	As Received	725 + 675	2	109	1/2	1/2
63	"	" "	725 + 675	2	128	2/3	1/3

1. Moderate Chill - stainless steel shims used between work and copper backup plate. Described in Figure
2. Wire "As Received" had slight "smut" on surface which had not been removed in production welding.
3. All aging treatments preceded by cooling at -100°F for 16 hours.
4. In most cases fracture occurred before reaching the 0.2% offset yield value.
5. Distribution of a brittle appearance on fracture surface of welds.

TABLE 65 (Continued)

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TENSILE PROPERTIES OF 20% NICKEL STEEL
VARIOUS SPECIAL CONDITIONS OF BASE METAL AND WELDS

Base Metal - 20% Cold Rolled
0.040 Inch Gage

Filler Wire Heat No. 7-C-088

Heat No. 24022
Treated as Shown

Spec. No.	Type	Heat Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation in 2 Inches			RC Hardness	Location of Fracture
					½"	1"	2"		
HNAT-26	Base Metal	Elec. resistance heated to 2150°F for 15 sec. in air. -100°F + 725°F, 3 hours.	143	157			1.5	37	-
-27			147	169			2.5	36.5	-
HNCT-36	Arc* Weld	Elec. resistance heated to 1500°F, 10 sec. in air. -100°F + 725°F, 3 hours.	179	181	2	1	.5	44	HAZ
-37			-	167	2	1	1	45	HAZ
NT-23	Arc* Weld	Furnace heated to 1500°F, 15 min., air cooled. -100°F + 725°F, 3 hours.	205	219	6	3	1.5	42	HAZ
-25			-	214	2	1	.5	42	BM
-27			201	214	6	3	1.5	44	HAZ

*Production made welds from Case NS-1

HAZ - Heat Affected Zone
BM - Base Metal

TABLE 66

The Budd Co.
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heated locally to 2150°F for 15 seconds in the gage area of the specimen using a resistance coil. This was an attempt to simulate the rapid temperature rise and the gradient experienced in welding and possibly duplicate, in an unwelded specimen, the metallurgical condition encountered in the low strength weld heat affected zone. Following the heating, the specimens were cooled at -100°F for 16 hours and then aged at 725°F for three hours. Results of tensile tests on these specimens are shown in Table 65. Tensile values were only slightly higher than the solution annealed properties of the base metal. Strength response to aging was insignificant, indicating the presence of a stable austenite. In addition, the failure was a brittle intergranular type. Another group of T.I.G. welded specimens were locally annealed by resistance heating to 1500°F for ten seconds, then air cooled. This was followed by aging at 725°F for three hours. Again, no significant change in properties resulted. A third group of specimens in this series were furnace annealed at 1500°F for 15 minutes, air cooled and aged at 725°F for three hours. Tensile values were at an expected level for the alloy. These results are also tabulated in Table 66.

Since no specific characteristic appeared as the cause for the low weld strength as a result of variations in welding conditions or techniques, it was suspected that composition variables or contaminating elements in the base metal or weld wire might be the cause. A series of bead on plate

specimens (no filler wire) were prepared. Tests were made of specimens in the "as welded" condition and after various aging treatments. Strengths of the "as welded" specimens were normal for the 20% nickel steel, however, strengths after aging were low and exhibited considerable scatter. All failures of aged welds occurred in the heat affected zone. The data are summarized in Table 67.

A series of weld tensile specimens were made using the base metal, .040 thick, 60% cold rolled to final gage, from heat 24022, but changing the filler wire to heat V00695, which has a slightly lower carbon content in the analysis. The analyses of filler wires and base metal are tabulated in Figure 34. Using the lower carbon analysis wire, the "as welded" strengths were high with good elongation. After aging at 725°F for three hours, the strengths were low and inconsistant. Specimens aged at 725°F for three hours, solution annealed at 1500°F 20 minutes, then reaged at 940°F three hours, resulted in very high yield strength. The strengths of this series are shown in Table 68.

During the same period that weld strength investigation was underway at The Budd Company Laboratory, the International Nickel Company's Bayonne Research Laboratory ran a series of tests in an attempt to find a specific solution to the problem. Helical weld specimen taken from the NS-3 case were aged and tested at INCO. Specimens

TENSILE PROPERTIES OF 20% NICKEL STEEL
BEAD-ON-PLATE WELDS*

Material - Cold Rolled 60%
0.040 Inch Gage

Center or End of Coil as Noted

Heat No. 24022
Treated as Shown

Spec. No.	Location of Coil	Treatment	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation ½"	Elongation 1"	Elongation 2"	Location of Fracture
HNCT-70	Center	"As Welded"	142	145	9	5	2.5	Weld
-71	Center	"As Welded"	134	141	12	6	3	HAZ
-72	Center	725°F, 3 hrs.	-	165	2	1.5	1.0	HAZ
-73	Center	725°F, 3 hrs.	-	161	4	2	1	HAZ
-78	Center	(350°F, 18 hrs. + (725°F, 3 hrs.	-	162	4	2	1	HAZ
-79	Center	(350°F, 18 hrs. + (725°F, 3 hrs.	-	167	4	2	1	HAZ
HNCT-74	End	"As Welded"	133	140	12	6	3	Weld
-75	End	"As Welded"	133	139	10	5	3	Weld
-76	End	725°F, 3 hrs.	-	169	6	3	1.5	HAZ
-77	End	725°F, 3 hrs.	-	171	6	3	1.5	HAZ
-80	End	(350°F, 18 hrs. + (725°F, 3 hrs.	-	164	3	1.5	1	HAZ
-81	End	(350°F, 18 hrs. + (725°F, 3 hrs.	-	135	3	1.5	1	HAZ

*Normal Chill (See Figure

HAZ - Heat Affected Zone

TABLE 67

The Budd Co.
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CHEMICAL ANALYSES OF 20% NICKEL MAR-AGING STEEL, STRIP AND WELD WIRE

	Heat No. 24022		Heat No. 7-C-088			V00695	Sample From Helical Weld
	.040 Strip Ladle Analysis	.040 Strip 60% Cold Rolled	Weld Wire Ladle Analysis	.032 Dia. Weld Wire	.032 Dia. Weld Wire Cleaned	.032 Dia. Weld Wire	
C	.008	.014	.029	.035	.030	.003	-
Mn	.008	.010	.003	.012	-	.01	-
P	.004	.005	.008	.007	-	.001	-
S	.005	.006	.007	.007	.003	.003	-
Si	.019	.012	.005	.047*	-	.02	-
Ni	19.97	19.81	19.72	20.28	-	20.35	-
Ti	1.85	1.85	1.62	1.70	-	1.68	-
Cb	.42	-	.43	.45	-	-	-
Al	.47	.48	.26	.25	-	.42	-
B	.001	-	-	-	-	.002	-
Lr	.018	-	-	-	-	.02	-
Cr	-	-	.006	-	-	-	-
H_2	-	3.2 PPM	-	(8.1 (12.6 PPM	-	-	5 PPM
N_2	-	33.2 PPM	-	42.8 PPM	-	-	-
O_2	-	39.0 PPM	-	236. PPM	-	-	-

*Analyses made by International Nickel Corporation and Allegheny-Ludlum Steel Corporation.

FIGURE 34

The Budd Co.
12-62

TENSILE PROPERTIES OF 20% NICKEL STEEL
LABORATORY T.I.G. WELDS - LOW CARBON FILLER WIRE

Base Metal - Cold Rolled 60%
0.040 Inch Gage

Filler Wire Heat No. V00695[1]

Heat No. 24022
Treated as Shown

Spec. No.	Condition[2]	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% Elongation ½"	% Elongation 1"	% Elongation 2"	Location of Fracture
A	"As Welded"	173	175	7	3.5	1.5	HAZ
B	"As Welded"	170	172	6	3.5	1.5	HAZ
C	725°F, 3 hrs.	-	139	4	2	1	HAZ
D	725°F, 3 hrs.	-	172	4	2	1	HAZ
E	725°F, 3 hrs. +	-	193-304[3]	2	1	1	Weld
F	1500°F, 20 min.	188-312	191-318[3]	4	2	1	Weld
G	+ refrigeration	315	322	4	2	1	HAZ
H	+ 940°F, 3 hrs.	306	314	6	3.5	1.5	Base Metal

HAZ - Heat affected zone.

1. See Figure for wire analysis.
2. All aging treatments preceded by -100°F, 16 hours.
3. Higher value calculated on base metal thickness; fracture occurred through weld.

TABLE 68

The Budd Co.
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were welded at the INCO Laboratory using .040 inch thick base metal from heat No. 24022 and weld wire from heat No. 7-C-088 furnished by The Budd Company and various aging temperatures were employed. Weld wire was used on a group of specimens, which had been baked at 600°F for 20 hours to reduce the hydrogen content. The hydrogen content was reduced to 6 ppm from 8 to 12 ppm as a result of this heating.

The results of this work, as reported by International Nickel Company, are shown in Table 69. In general, these results are quite similar to those obtained by The Budd Company. Low ductility, fusion line failures were experienced at lower strength levels than required for the case design.

Some observations made by INCO Laboratory personnel are:

1. The low strength aging response of the 20% nickel, high hardness composition alloy, is not due to any one outstanding item, which, if corrected, would be a cure. They feel it is an accumulation of several aggravating items which added together cause the problem.

2. The higher content of hydrogen and oxygen in the weld wire are not pertinent to the problem. They could possibly be aggravating elements which contribute to the low strength response.

TENSILE PROPERTIES - 20% NICKEL STEEL
T.I.G. WELDED SPECIMENS

All specimens heat treated and tested at International Nickel Company - Bayonne Laboratories

.040 Thick Strip - 60% Cold Reduced

Base Metal Heat No. 24022
Weld Wire Heat No. 7-C-088

Specimen Description	Yield Strength KSI	Tensile Strength KSI	Tensile Strength Range KSI	Elong. % 1"	Area of Failure
Budd Helical Weld - NS-3 Case As Welded - Bead On	152	162	139-162	2.5	Weld
Budd Helical Weld - NS-3 Case As Welded - Flush Weld	138	141	138-142	2.0	Weld
Budd Helical Weld, Aged 725°F, Bead On	-	97	91-109	-	Fusion Line - HAZ
Budd Helical Weld - NS-3 Case Aged 725°F - Flush Weld	-	174	167-180	-	Fusion Line - HAZ
Budd Helical Weld - NS-3 Case - Anneal 1500°F, Age 900°F, 3 hrs. - Bead On	-	255	216-274	-	Fusion Line - HAZ
Inco Weld - Age 725°F - Bead On	204	204	196-210	-	Fusion Line - HAZ
Inco Weld - Age 725°F - Flush Weld	167	171	168-175	-	Weld
Inco Weld - Age 725°F - Bead On - Wire Baked 600°F, 20 hrs. H_2 - 6 PPM	-	141	129-153	-	Fusion Line - HAZ
Inco Weld - Age 725°F - Flush Weld - Wire Baked 600°F, 20 hrs. H_2 - 6 PPM	-	164	159-169	-	Fusion Line - HAZ
Inco Weld - Bead On Plate - Age 725°F.	186	187	184-189	-	Weld
Inco Weld - Bead On Plate - Age 725°F - Edge Notch Specimen	G_c = 630-930. Slow failure of one specimen initiated in fusion line of weld, not at root of notch. Rapid fracture then moved to weld centerline.				

TABLE 69

The Budd Co.
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3. The welding required a considerable reduction in restraint of the fixture to prevent centerline cracking in the weld bead. The alloy under high restraint is crack sensitive, probably due to the hardening elements in the composition (Ti, Al, and boron).

4. Stress concentrations due to mismatch, bead height and bead edge conditions could aggravate and add to the problem.

5. INCO has found that boron, when added to high nickel alloys which are subsequently annealed at high temperature or welded, suffer a marked decrease in ductility. Since boron was in the composition of the 20% alloy used by Budd (.001%), it can be assumed that the low ductility in the heat affected zone is due in some degree to the presence of this element.

International Nickel Company's recommendation after review of data from weld specimens evaluation wire.

1. Nickel mar-aging steels having high quantities of the hardening elements, titanium and aluminum, should be avoided in favor of a leaner, more "standard" analysis.

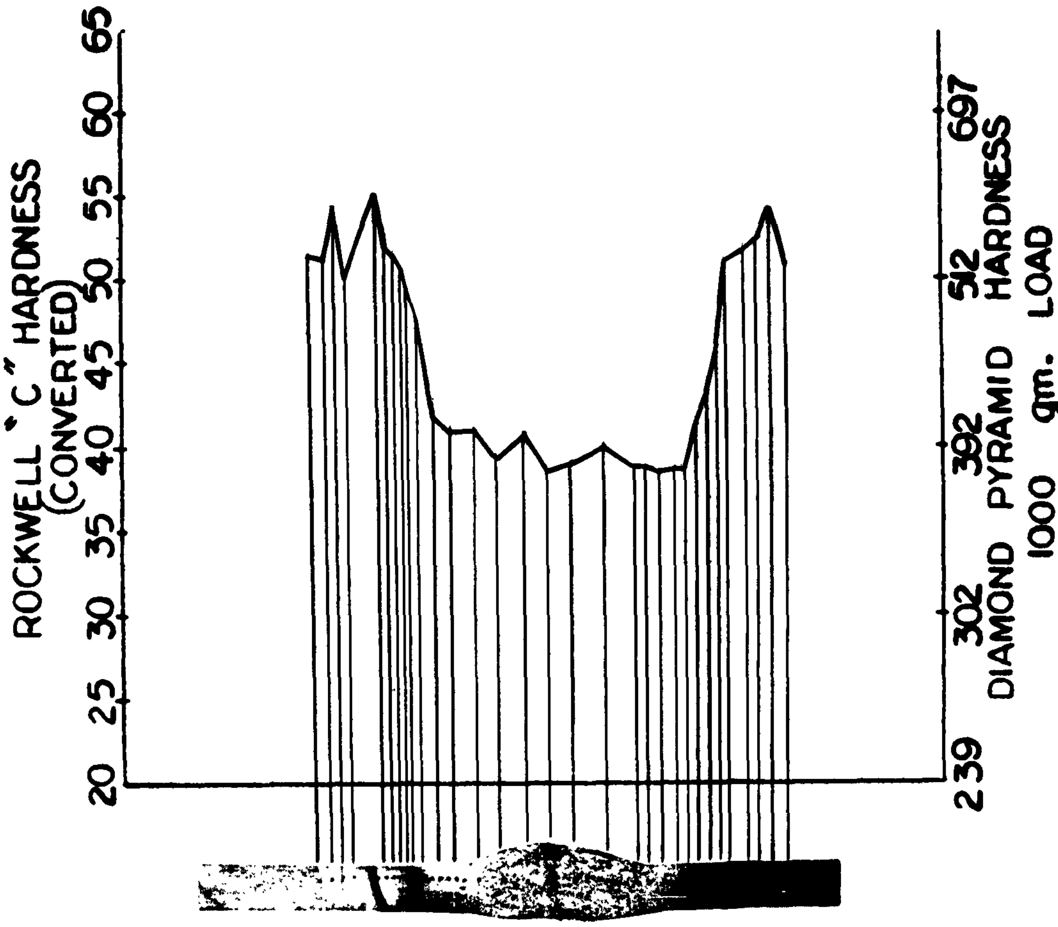
2. Boron should be deleted from the composition as this element has been found to cause a reduction in ductility when the base metal is held in a high temperature (1800°F-2000°F) for even a short period of time.

3. The experience with the 18% nichel-cobalt-moly grades has been much more satisfactory, particularly the uniform strength response to aging of welds. The brittle fusion line failures, erratic variations in strength values, and extreme sensitivity to weld geometry were not experienced.

Two typical hardness traverses, representative of many made, across the weld specimen are shown in the photomacrograph and curve in Figures 35 and 36. Both specimens were T.I.G. welded, .040 thick strip, which had been cold reduced 60% to final thickness. One specimen had been aged at 725°F for three hours and the other was aged at 725°F for three hours, followed by reaging at 675°F for three hours. These are the treatments used on the test case. An approximate weld size can be seen from the macrophotograph. The hardness variations are about as expected for the heat treatment. A base metal hardness of R_c 53-54, with a sharp increase in the heat affected zone to R_c 55-57, then a reduction in the weld deposit area to a level of R_c 38-43. There is no significant difference in the hardness variations between the single and

MICRO HARDNESS TRAVERSE

WELD CROSS SECTION
KENTRON MICRO HARDNESS TESTER
DIAMOND PYRAMID PENETRATOR



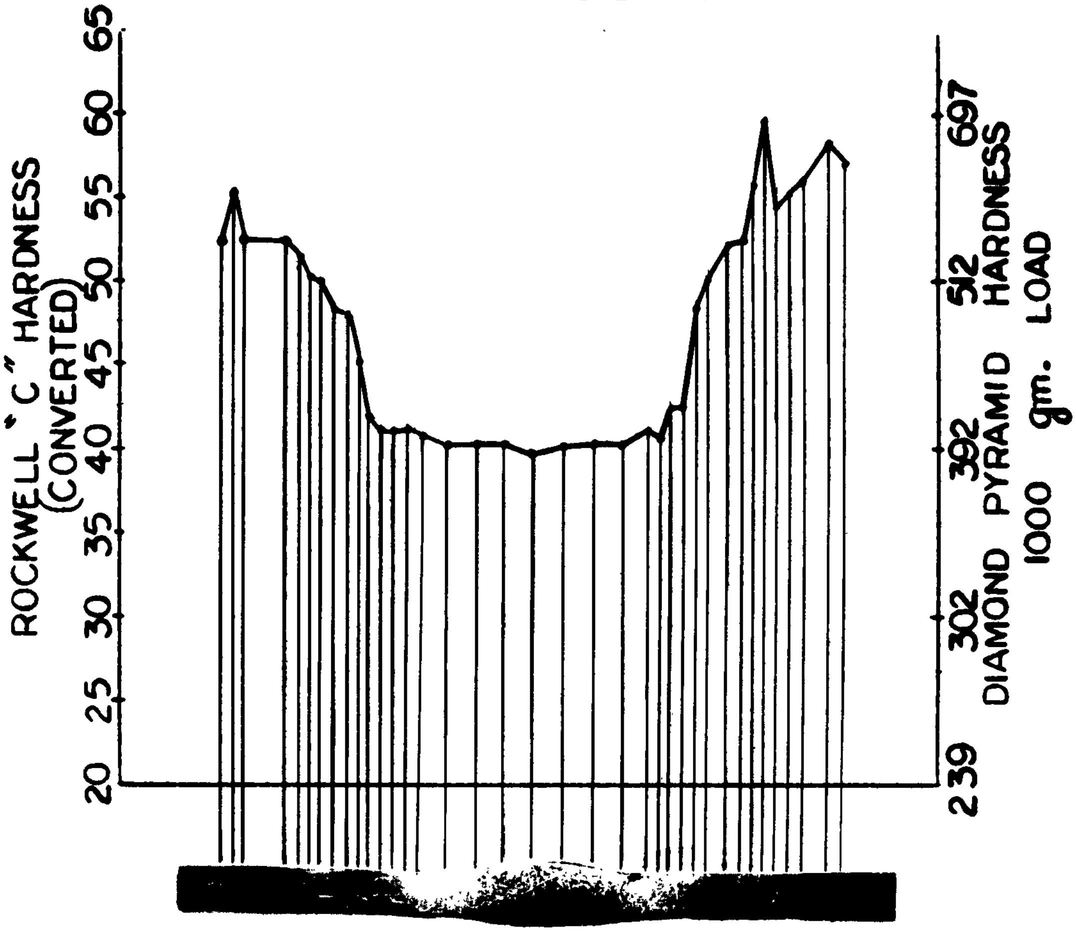
SPEC. NO. HN050 WELD TYPE T.I.G. MAG. 5 X
ETCHANT Fry's Reagent

MATERIAL 20% Nickel Mar-aging Steel GAGE .040
CONDITION Cold Rolled 60%, Lab. Welded, Cooled -100°F, 16 Hours, Aged 725°F, 3 Hours.
WELD SIZE Height .080; Width 0.23

FIG. 35

MICRO HARDNESS TRAVERSE

WELD CROSS SECTION
KENTRON MICRO HARDNESS TESTER
DIAMOND PYRAMID PENETRATOR



SPEC. NO. HN054 WELD TYPE T.I.G. MAG. 5 X

ETCHANT Fry's Reagent

MATERIAL 20% Nickel Mar-aging Steel GAGE .040

CONDITION Cold Rolled 60% Helical Welded, Sub-zero Cooled -100°F, 16 Hours, Aged 725°F, 3 Hours, Sub-zero Cooled, Aged 675°F, 16 Hours.

WELD SIZE Height .080; Width 0.20

FIG. 36

double aged specimens.

A series of photomicrographs of T.I.G. weld specimens were made in an attempt to find a characteristic which could be identified with the low strength response of the weld to aging. Shown are some typical photomicrographs of representative welds on the .040 thick 20% nickel steel, cold reduced 60%, which are in the "as welded" condition, (Figures 37 and 38), double aged at 725°F and 675°F, (Figure 39) and single aged at 725°F, (Figure 40). Figure 41 shows unwelded tensile specimens, which were resistance heated to 2150°F for ten seconds to simulate the rapid heating occurring during welding and a similarly heated specimen which was aged at 725°F for three hours.

Examination of micrographs of T.I.G. welds having various heat treatments did not reveal any significant structural characteristic that could be identified and established as a specific cause of low strength response of welds to aging. These were examined by Laboratory personnel at The Budd Company and at the International Nickel Company Research Laboratory in Bayonne, New Jersey.

A specific cause for low weld strength response to aging did not appear as a result of this program. The investigation was not in itself a complete study of the problem, but was rather an attempt to isolate the cause by introducing the more obvious conditions that might reveal

20% NICKEL MAR-AGING STEEL
Base Metal Heat 24022 Weld Wire 7-C-088
As Welded Condition - Helical Weld
Etchant: 1% Picral / 5% H_{cl}; Swabbed 40 Sec.

Mag: 1300 X Right Side of Weld Bead

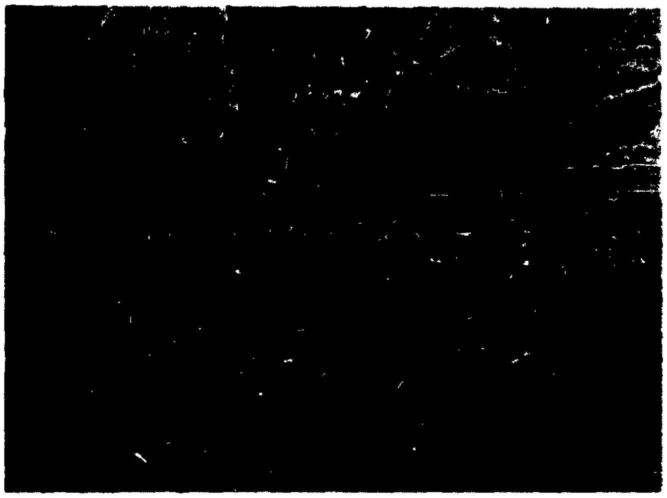
Structure adjacent to fusion line, austenite grains with untempered martensite. Some intergranular precipitation.

Mag: 1300 X Left Side of Weld Bead

Same condition as above, except on left side of weld bead less pronounced grain boundry precipitation.

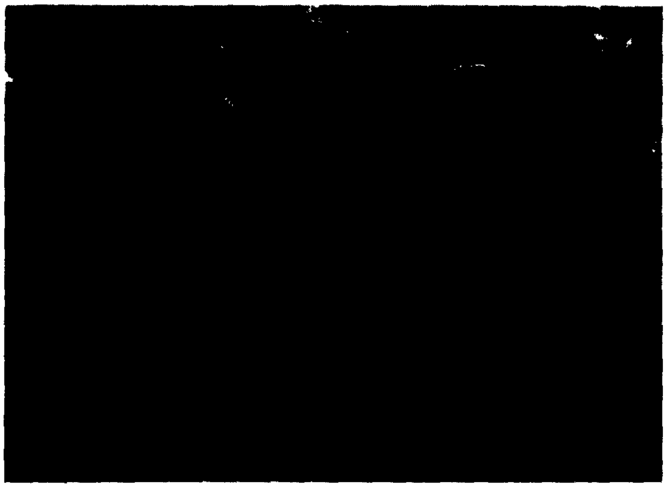
Figure 37

20% NICKEL MAR-AGING STEEL
Base Metal Heat 24022 Weld Wire 7-C-088
As Welded Condition - Helical Weld
Etchant: 1% Picral / 5% H_{cl}; Swabbed 40 Sec.



Mag: 1300 X Right Side of Weld Bend

Structure adjacent to fusion line, austenite grains with untempered martensite. Some integranular precipitation of carbides.



Mag: 1300 X Left Side of Weld Bead

Same condition as above, except on left side of weld bead more pronounced intergranular precipitation.

Figure 38

20% NICKEL MAR-AGING STEEL

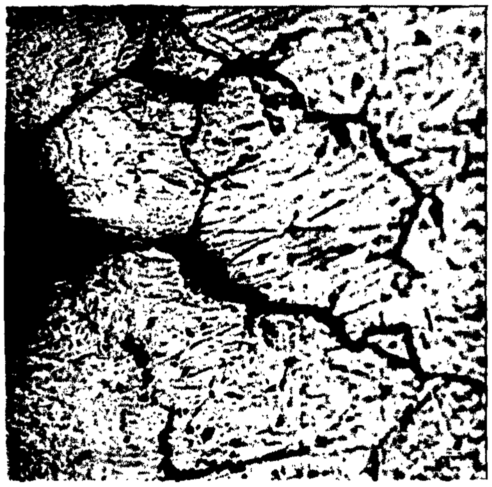
Base Metal Heat 24022 Weld Wire 7-C-088

Helical Weld - Mar-aged 725°F, 3 Hours Plus 675°F, 3 Hours

Etchant: 1% Picral + 5% H_{cl}

Mag: 100 X Weld Deposit HAZ

Fracture Line of Tensile Specimen. Tensile Strength 80 KSI. Note Extensive Intergranular Cracking.



Mag: 1000 X

Heat Affected Zone

Intergranular Cracking in Heat Affected Zone Adjacent to Fusion Line.

Figure 39

20% NICKEL MAR-AGING STEEL
Base Metal Heat 24022 .040 Thick Strip 60% Cold Reduced
T.I.G. Helical Weld Weld Wire Heat 7-C-088
Etchant: 1% Picral / 5% H_{cl}

Mag: 1000 X

Weld Heat Affected Zone. Specimen Colied -100°F, 16 Hours Plus Mar-age 725°F, 3 Hours. Austenite Grains Containing Martensite. Grain Boundary Contains Some Carbide Particles.

Figure 40

20% NICKEL MAR-AGING STEEL

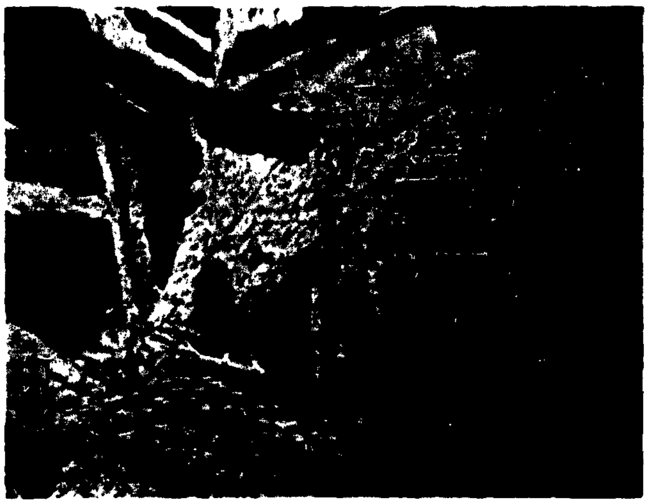
Base Metal Heat 24022 .040 Thick Strip

60% Cold Reduced Weld Wire Heat 7-C-088

Etchant: Fry Reagent

Mag: 500 X

Specimen Strip Resistance Heated to 2150°F, 10 Seconds. Austenite Grains With Martensite Grain Boundries.



Mag: 500 X

Specimen Strip Resistance Heated to 2150°F, 10 Seconds, Followed By Cooling -100°F, 16 Hours, Plus Mar-age at 725°F, 3 Hours. Martensite in Austenite Grains and Grain Boundry Precipitation. Small Microcrack in Austenite Grain.

Figure 41

the answer. Time and funds did not permit a more complete investigation. It is obvious that more research is required to isolate the cause of the problem. Effects of small temperature differences in aging from 400°F to 1000°F on welds should be studied. Electron microscopy should be employed to examine structures where strength is low and compare them with high strength ductile weld areas. Examination of the material, subject to the identical temperature gradients encountered in the welding process from fusion temperature to room temperature should be made. It is firmly believed that there is a specific reason for the condition, since in the evaluation heat of the same composition consistently good aging response in the welds was obtained. However, results were not duplicated in a second heat of the identical alloy. Weld quality has been unusually good. Cracking and porosity are practically nonexistent.

<u>Alternate Heat Treat Procedure (Test Case No. NA-3)</u>

Hydrotesting of the two 20 inch diameter test cases, made from a high hardner analysis of 20% nickel mar-aging steel, was not carried out due to variable and low strength response of the helical welds to aging treatment. One case was sectioned to obtain tensile specimens, and the second case was re-solution annealed, sub-zero cooled, and aged in a salvaged attempt. Tests of control specimens from the re-solution annealed case showed some improvement, but the spread in values made the hydrotest inadvisable.

It was decided to attempt to circumvent the problem by a change in the process sequence and thermal treatments. This mainly included aging the strip material to full strength, followed by helical welding, then aging at a lower temperature in the 250°F to 450°F range.

A series of weld test specimens were prepared from aged strip at 290 ksi yield strength. They were sub-zero cooled and reaged at 250°F, 350°F and 450°F. At the same time, it was decided to maintain the helical weld strength in the case at about 54% of the base metal yield strength. This would be adequate due to the 11° helix angel, and at the same time ductility and toughness would be improved. Table 70 is a summary of the tensile specimen results of welds made on fully aged material, followed by a low temperature aging treatment. The results of this series was most encouraging. Values, while they were not as high as we would have liked, were consistent and the failures were of a ductile type.

Based on these data, it was decided to fabricate a 20 inch diameter test case for hydrotest.

The remaining 40 feet of coil stock was coiled to approximately a 20 inch diameter, sub-zero cooled at -100°F for 16 hours, and aged at 675°F for three hours, followed by air cool to room temperature. A thermocouple was installed between coil layers, approximately in the center

20% NICKEL MAR-AGING STEEL
T.I.G. WELDED SPECIMENS - AGED BASE METAL

.040 Thick Strip, Cold Rolled 60%
Base Metal Heat 74022

Aged 675°F, 3 Hours Prior to Welding
Filler Wire Heat 7-C-088

Specimen No.	Condition	0.2% Yield Strength KSI	Tensile Strength KSI	% Elongation ½"	% Elongation 1"	Location of Fracture
82	As Welded	167	168	7	3.5	HAZ
83		160	162	5	2.5	HAZ
84		153	157	5	2.5	HAZ
85	Weld	159	161	5	2.5	HAZ
86	-100°F, 16 hours	158	161	5	2.5	HAZ
87	Age 250°F, 3 hours	159	161	6	3.0	HAZ - Weld
88	Weld	169	171	7	3.5	HAZ
89	-100°F, 16 hours	169	170	8	4.0	Weld
90	Age 350°F, 16 hours	162	170	5	2.5	HAZ
91	Weld	179	181	5	2.5	HAZ
92	-100°F, 16 hours	180	180	5	2.5	HAZ
93	Age 450°F, 3 hours	184	185	6	3.0	HAZ

TABLE 70

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of the mass, to make sure all parts of the coil reached the aging temperature. An error in setting the master control on the furnace caused a rise to 720°F for 15 minutes in the first half hour. The temperature was brought down to the 675°F as quickly as possible, however, we expect this variance may have raised the yield strength slightly higher than we had desired.

The cylindrical section was welded in the fixture, using the same weld schedule as used in prior cylinders. Improved guide shoes were installed to better control mismatch and water cooling was introduced to hold down temperature in the chill blocks. The elliptical head was removed from case NA-2 for use on the new test case. The head was welded to the cylinder in a special welding fixture. All welds were visual and dye check inspected - no cracks were found. Reinforcing doublers were installed and the entire assembly complete with base metal and helical weld control specimens, located as shown in Figure 42, were sub-zero cooled at -100°F for 16 hours, followed by aging at 450°F for three hours. Control specimens were final machined and tested. Control tensile specimen results are shown in Table 71.

The control specimen results were satisfactory. Base metal yield strengths were slightly higher than the expected, probably due to the short time at the high aging temperature of 720°F. Aged yield strengths of the tensile specimens,

SERIAL NO. NA-4
20 INCH DIA. TEST CASE
LOCATION OF HEAT TREAT CONTROL SPECIMENS

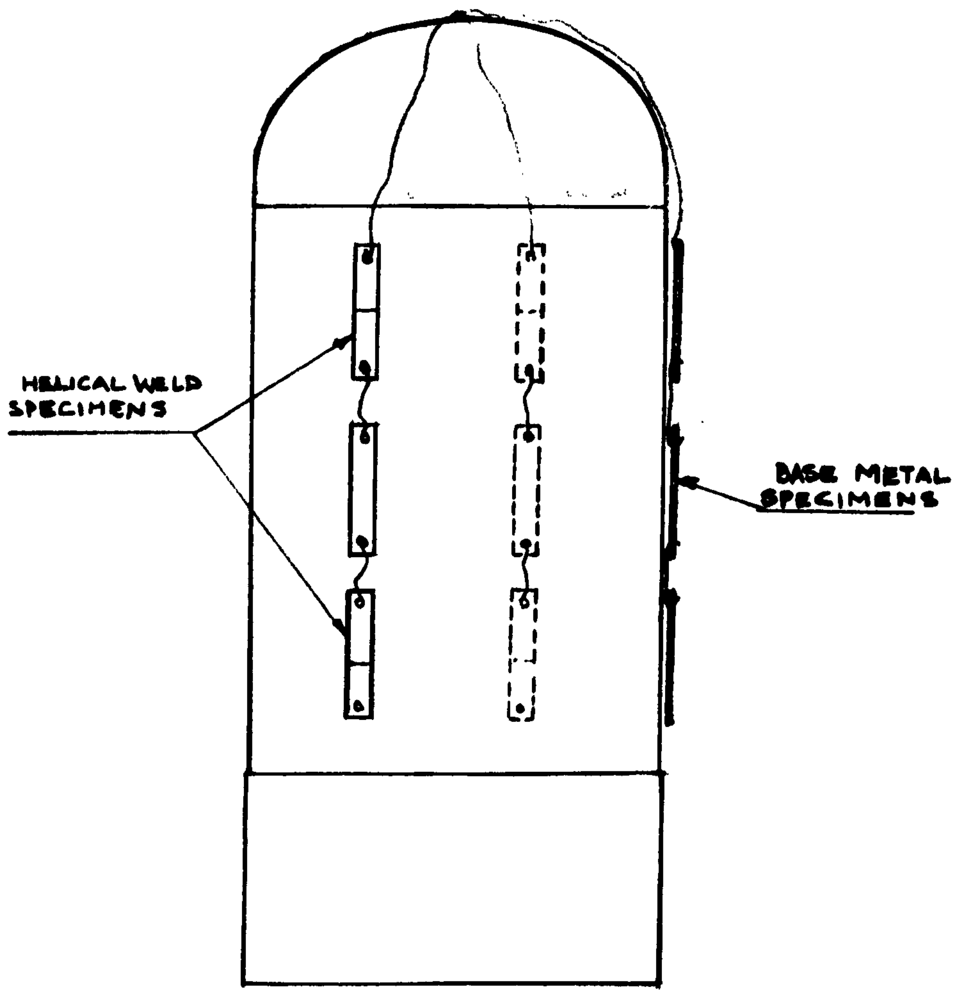

Figure 42

representing the helical welds, averaged 176,000 psi yield or 58% of the base metal yield strength. This met the design requirements and it was decided to hydrotest the case.

20% NICKEL MAR-AGING STEEL
BASE METAL AND HELICAL WELD CONTROL SPECIMENS
TEST CASE NA-4

.040 Thick Strip, Cold Rolled 60%
Base Metal Heat 7-C-088

Aged 675°F, 3 hours + 450°F, 3 hours
Filler Wire Heat 7-C-088

Specimen No.	Case Area Represented	0.2% Offset Yield Strength KSI	Tensile Strength KSI	Elongation in 2 Inches
MS-4-4	Base Metal Cylindrical Section	-	307	1%
MS-4-5		304	304	1%
MS-4-6		305	306	Outside Gage Length
WS-4-3	Helical Weld Cylindrical Section	175	178	1%
WS-4-4		174	177	1%
WS-4-5		175	176	1%
WS-4-6		178	179	1%
WS-4-7		179	180	1%
WS-4-8		177	178	1%

TABLE 71

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HYDROTEST OF 20 INCH DIAMETER TEST CASE (MA-3)

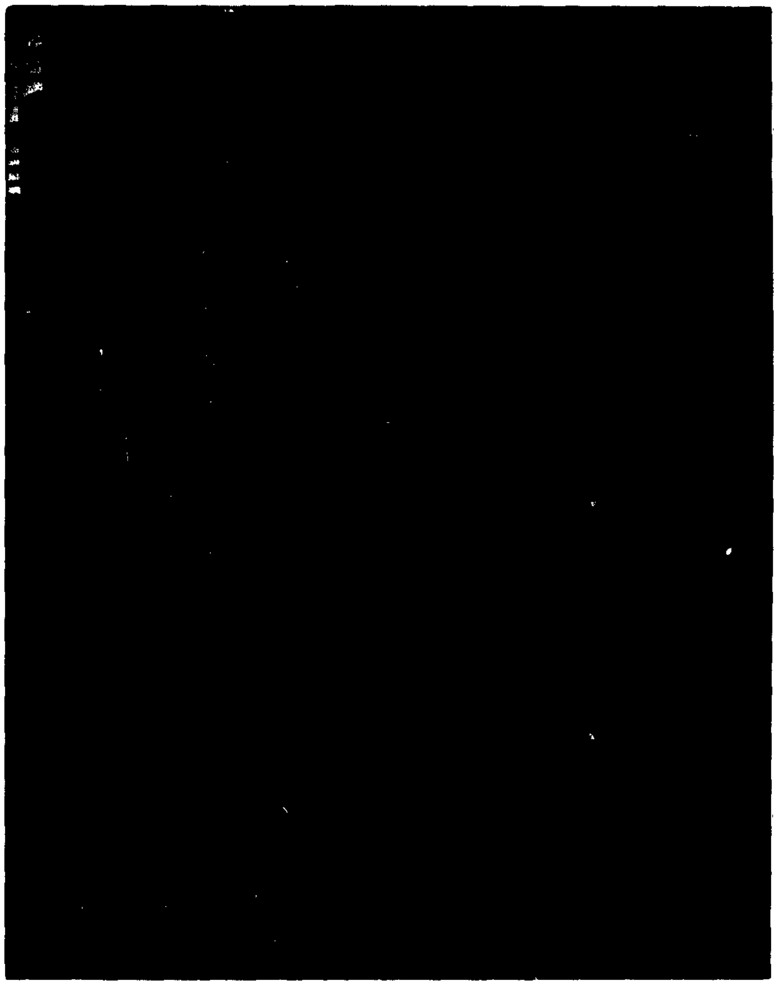
The 20 inch diameter test case No. MA-3 was prepared for hydrotest. The case was supported vertically in a test stand with the elliptical head in the down position. The case was bolted in the test stand through the aft plug. The general arrangement is shown in Photograph Figure 43.

Four "T" type strain gages were applied to the outside surface of the case. One pair was located as close as possible to the helical weld and a second pair was located in the base metal area, midway between the helical welds. A displacement transducer was mounted in contact with the center of the elliptical head. The gages and transducer were connected to recording instrumentation to record the strains and any changes in length due to pressurization. The photograph, Figure 44, shows the location of the gages and displacement transducer.

Figure 45 is a photograph showing the instruments employed to record strains, dimensional change, pressure increments and the hydraulic pump used as a source of pressure.

The pressurizing medium used in the hydrotest as a non-corrosive hydraulic oil.

All instrumentation was checked out for zero reading and pressure applied to the case in 200 psi increments. Strain gage, pressure transducer and displacement transducer readings were taken at each increment. The case burst at 770 psi pressure. This was equivalent to a hoop stress in the base metal of 63% of the tensile strength of the material. Table 72 is a summary of test results. Figure 46

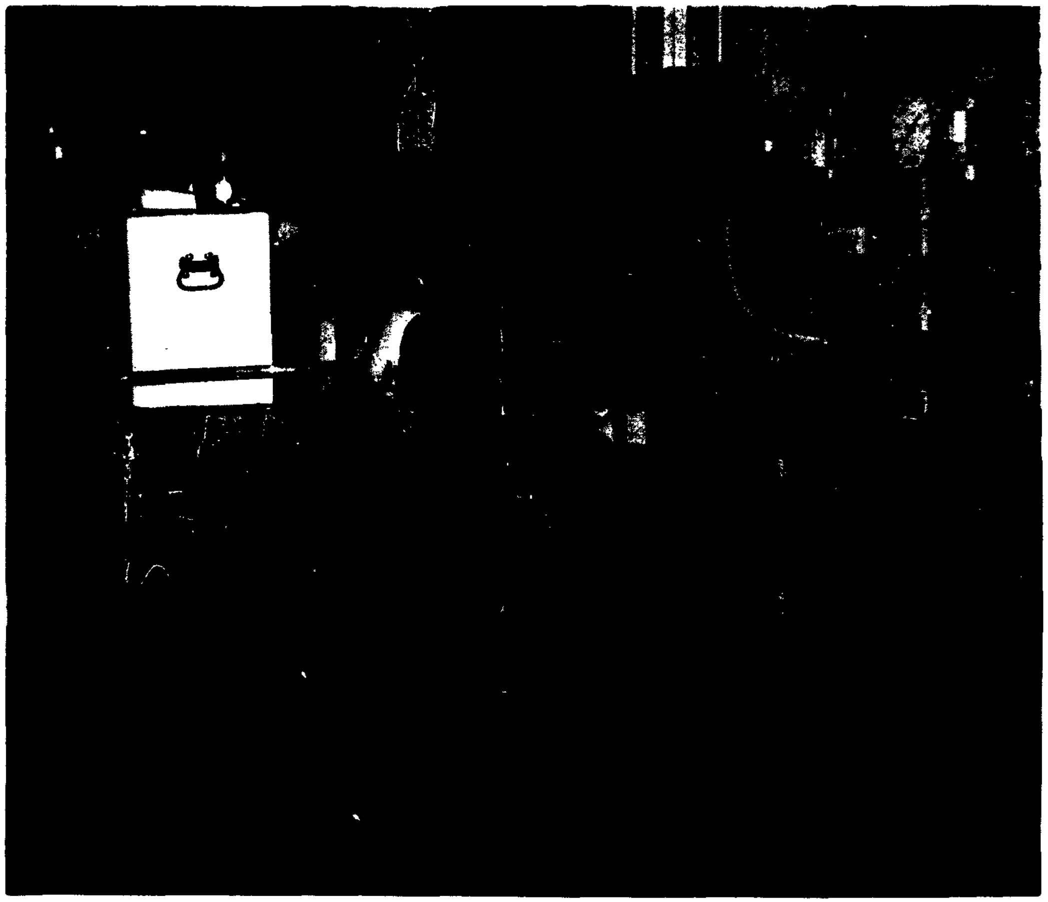


20 Inch Diameter, 20% Nickel Mar-aging
Steel Test Case Prior to Hydrotest

Figure 43

20 Inch Diameter 20% Nickel Steel Test Case
Prior to Hydrotest - Strain Gage Locations are Shown

Figure 44



General View of Recording Instrumentation, Hydraulic Pumps and Gages Used in Hydrotest

Figure 45

SUMMARY OF HYDROTEST
20 INCH DIAMETER - 42 INCH LONG CASE
20% NICKEL MAR-AGING STEEL (HEAT 24022)

Case Number	Pressure at Burst PSI	Hoop Stress at Burst PSI (Calculated)	Ratio - Burst Hoop Stress to Base Metal Tensile Strength	Location of Origin of Failure	Length Increase at Burst Pressure Inches	Hoop Stress Based on Strain Gage PSI	Stress Normal to Weld Strain Gage PSI
NA-3	770	192,000	0.63	Base Metal in Cylinder between Helical Welds	0.110	156,000	28,300

SUMMARY OF UNIAXIAL PROPERTIES OF MATERIAL IN CASE NA-3

	Yield Strength PSI	Tensile Strength PSI
Cylinder Base Metal	307,000	308,000
Helical Weld	178,000	179,000
Elliptical Head	280,000	290,000
Head - Shell Weld	178,000	179,000

TABLE 72

Failure Originated
on This Side

Side Opposite to
Failure Origin

20 Inch Diameter, 20% Nickel Mar-aging Steel
Test Case After Hydrotest

Figure 46

is a photograph showing two views of the case after burst test. One view is taken from the side where the failure originated.

An examination of the burst case was made to determine, if possible, the cause of the failure at low pressure. The parts were reassembled into their original position and the direction and sequence of failure was determined. Figure 47 is a diagramatic sketch showing the origin of failure at burst and the pattern of secondary failures. As shown in the sketch, the failure started in the base metal in approximately the center of the panel adjacent to the rear doublers. The failure then progressed longitudinally across the helical welds. Secondary effects were peripheral breaks in the base metal and along the weld heat affected zones. It should be noted that there was no evidence of failure initiation in the welds. In addition, secondary breaks along welds represent only about 20% of the total failure pattern. The welds actually served to stop the progression of breaks. The failure was of a tension type with good evidence of necking and 45° shear planes. The degree of necking indicated considerable ductility in the base metal at the 305,000 psi yield strength.

The general area of failure origin having been determined, a more detailed examination was made of this area. This is the shaded section shown in Figure 47.

Close examination of the origin area revealed a series of surface defects oriented in a line normal to the rolling direction of the strip. This line of defects begins outside of the failure line, running into the failure line for a short distance and then emerging on the

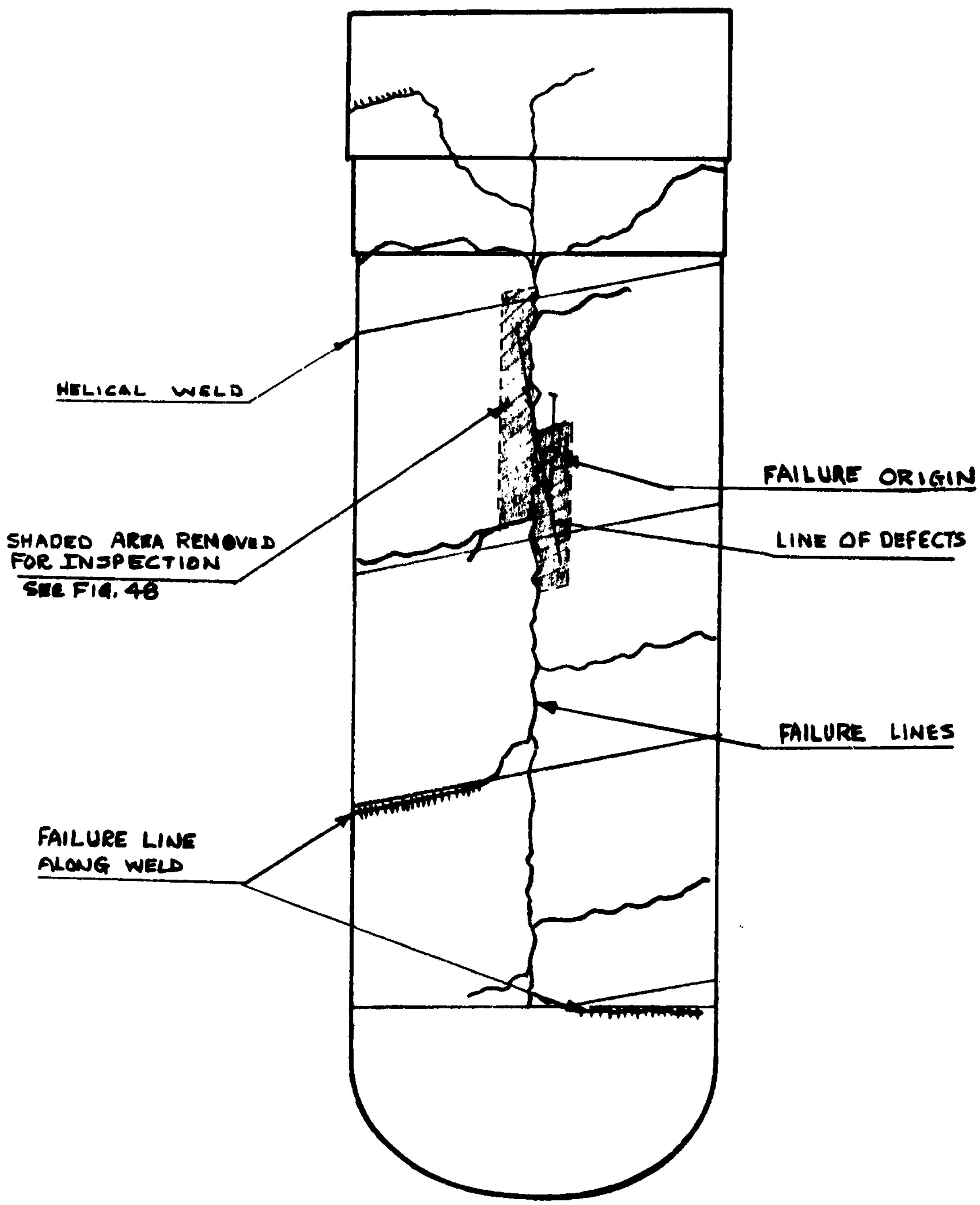


Figure 47

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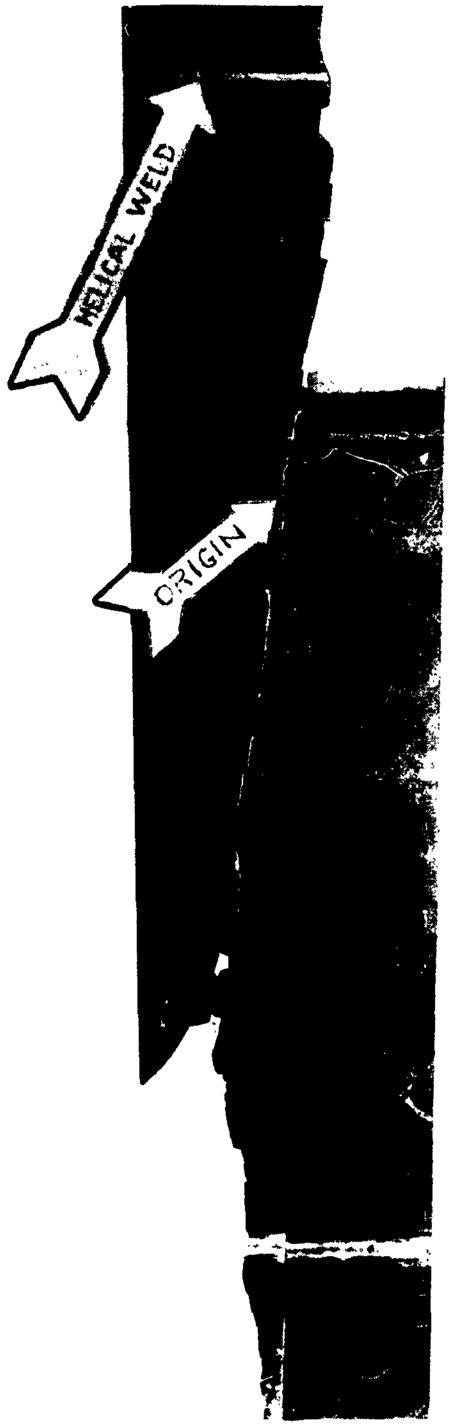
other side of the break. Figure 48 is a photograph of the origin area removed from the case after hydrotest. The line of defects are in evidence in this photograph. Closer examination of the surface defects adjacent to the break had not failed, showed definite evidence of yielding and necking when viewed from the surface of metal opposite the defect. This is further evidence that the surface defects provided a stress concentration area which caused the premature failure. These defects had as much depth as 10% of the metal thickness, which reduces the next sectional area and increases the stress to the point where failure occurs. These appeared to be ductile failures and failure was not due to the propagation of an internal crack in a brittle manner.

In evaluation work on the 20% nickel mar-aging steel in strip form with various amounts of cold reduction, no defects such as caused the premature failure appeared on the surface. It is felt that such a condition is rare in material processed into strip product.

The following conclusions are drawn from the hydrotest:

1. The failure was premature and occurred at 63% of the base metal tensile strength due to surface defects in the base metal. The case failed longitudinally across the helical welds. The origin was not in the weld or weld area.

2. The failure pattern longitudinally across the welds indicated a satisfactory design concept.



Hydrotest of 20 Inch Test Case
Close-up Photograph of Area Where Failure Originated.
Note Line of Surface Defects or Pits Passing Through Origin.

Figure 48

3. The girth weld joining the elliptical head to the cylinder performed satisfactorily at the pressure attained. This includes the area where the helical weld intersects the girth weld.

4. Additional tests must be conducted to either prove or disprove the concept at maximum pressure.

CONTROLLED INGOT SOLIDIFICATION STUDIES

In accordance with recommendations made by the Technical Supervisor, Frankford Arsenal and the sponsor of The Rocket Case Development Program, Ordnance Materials Research Office, Watertown Arsenal, a subcontract was negotiated with Massachusetts Institute of Technology (M.I.T.) to continue their research on controlled solidification of ingots to attain maximum soundness in the castings and improved mechanical properties.

For approximately ten years The Foundry Division of the Department of Metallurgy at M.I.T. has conducted basic research on the solidification of metals and the development of techniques for producing castings and ingots with optimum soundness, homogeneity and mechanical properties. This work was primarily on the solidification of aluminum and high strength low alloy steels. The main emphasis has been to: (1) examine the effects of solidification variables on structure, segregation and properties of ingots and castings; and (2)

the development and testing of methods for obtaining directional solidification in cast steel. In this work, solidification of castings was controlled so that freezing took place under a variety of carefully controlled thermal conditions. Soundness and segregation were evaluated on a micro and macro scale, and correlation was made with solidification variables. It was determined that to control microporosity and segregation, it is necessary to adequately control solidification variables.

M.I.T. has developed techniques for promoting directional solidification and have successfully cast ingots free of macrosegregation and microporosity with microsegregation reduced to a very fine order of magnitude. The steels are cast in special moulds, which allows the heat to be extracted from the bottom of the ingot and not from the sides. This method produces a unidirectional grain structure aligned from top to bottom of the casting.

The objective of this subcontract is to extend the studies to relate ingot solidification variables to the mechanical properties of sheet material produced from these ingots.

Ingots were cast and solidification variables were examined for two alloys. These alloys were AISI 4340 and International Nickel Company's 25% nickel mar-aging steel. Ingots were cast using unidirectional solidification process and standard casting techniques. The AISI 4340 ingots were cast in both air and vacuum, whereas the 25% nickel was melted and cast only in vacuum. The quantity and type of each category of ingot evaluated are summarized as follows:

1. AISI 4340 Steel

    2 air melt - standard solidification

    4 air melt - unidirectional solidification

    2 vacuum melt - standard solidification

    4 vacuum melt - unidirectional solidification

2. 25% Nickel Mar-aging Steel

    2 vacuum melt - standard solidification

    4 vacuum melt - unidirectional solidification

All ingots produced by M.I.T. were approximately four inches in diameter and four inches long, weighing from 15 to 17 pounds.

Conversion of all ingots into approximately .040 inch thick sheet was made at the Research Laboratory of the United States Steel Corporation, Monroeville, Pennsylvania.

At this writing, the AISI 4340 air melt sheet product has been tensile tested at The Budd Company and these data are in Report No. 21. The balance of tensile testing and fracture energy testing will be completed at Frankford Arsenal in the near future.

The complete report on this work is in preparation at M.I.T., and it is estimated that several months will be required for completion. The results of the research work conducted at M.I.T. on the subcontract will therefore not be included in this report.

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Development of High Performance Rocket Motor Case
Final Summary Progress Report No. 23 - Period June, 1960 to November, 1962
by R. C. Dethloff and W. J. Hauck

Unclassified Report

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The results of work performed during the contract period June, 1960 to November, 1962 on the development of a high performance rocket motor case using high strength sheet and strip metal are discussed. Metallurgical evaluation of 12 ferrous and nonferrous alloys; selection of 20% nickel mar-aging steel for application to case; design of a 20 inch diameter by 40 inch long test case; development of a helical welding technique for fabricating cylinders from strip; development of a process to form hemispherical and elliptical heads from low elongation alloys; fabrication and hydrotest of a 20 inch test case; unidirectional ingot solidification of AISI 4340 and 25% nickel mar-aging steels are summarized.

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5. Elliptical Head Forming.
6. 20% Nickel Mar-aging Steel Fabrication.
7. Fabrication and Hydrotest of 20 Inch Helical Welded Case.
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